660.5 v.18

LIST OF THE OFFICERS

OF

The Institution of Petroleum Technologists,

1932-1933.

Past Presidents:

*Sir Boverton Redwood, Bart., D.Sc., F.R.S.E. (1914-1916).
Prof. Sir John Cadman, G.C.M.G., D.Sc., M.Inst.C.E., M.Inst.M.M. (1916-[1917).
The Rt. Hon. Lord Greenway of Stanbridge Earls (1917-1919).
*Sir Frederick W. Black, K.C.B., B.A. (Lond.) (1919-1921).
Prof. John Samuel Strafford Brame, C.B.E., F.I.C., F.C.S. (1921-1923).
*Herbert Barringer, M.Inst.C.E., M.I.Mech.E., M.I.N.A., M.Inst.Mar.Eng. (1923-1925).
Sir Thomas H. Holland, K.C.S.I., K.C.I.E., D.Sc., F.R.S. (1925-1927).
Alfred C. Adams (1927-1929).
A. E. Dunstan, D.Sc., F.I.C., F.C.S. (1929-1931).

President:

James Kewley, M.A., F.I.C., F.C.S., M.I.Chem.E.

Vice-Presidents:

Sir John T. Cargill, Bart., Hon., LL.D.
A. E. Chambers, A.M.Inst.C.E.
T. Dewhurst, A.R.C.Sc., F.G.S.
Alexander Duckham, F.C.S.
Arthur W. Eastlake, M.I.Min.E., A.M.I.Mech.E.
A. Beeby-Thompson, O.B.E., M.I.Mech.E., M.Inst.M.M., F.G.S.

Members of Council:

Lieut.-Col. S. J. M. Auld, O.B.E., M.C., D.Sc.
Ashley Carter, A.M.I.Mech.E.
G. H. Coxon.
A. Frank Dabell, M.I.Mech.E.
Christopher Dalley, M.I.E.E.
B. J. Ellis.
F. H. Garner, Ph.D., M.Sc., F.I.C.
T. R. H. Garrett, M.A., F.G.S.
John Gillespie, M.I.Mech.E.
Prof. V. C. Illing.
J. S. Jackson, B.Sc., A.I.C.
Prof. A. W. Nash, M.Sc., F.C.S., M.I.Mech.E.
J. McConnell Sanders, F.I.C., F.C.S.
F. B. Thole, D.Sc., F.I.C., F.C.S.
A. Wade, D.Sc., A.R.C.S., F.G.S., M.Inst.M.M., F.Am.G.S.

Honorary Treasurer: Rt. Hon. Lord Plender of Sundridge, G.B.E.

Solicitors: Messrs. Ashurst, Morris, Crisp & Co.

Auditors: Messrs. Price, Waterhouse & Co.

* Deceased.

Bankers:
WESTMINSTER BANK, LIMITED.
21, Lombard Street, London, E.C. 3.

Hon. Editor:
A. E. DUNSTAN, D.Sc., F.I.C., F.C.S.

Associate Editor and Secretary Standardization Committee:
GEORGE SELL.

Hon. Secretary:
ARTHUR W. EASTLAKE, M.I.Min.E., A.M.I.MechE.

Secretary:
Commander R. E. STOKES-REES, R.N.

Offices—Aldine House, Bedford Street, Strand, London, W.C. 2.
Telegraphic Address: "Instpetech, Lesquare," London.
Telephone: Temple Bar 1842.
Code: Bentley's (Oil Edn.).

COMMITTEES:

AWARDS, BENEVOLENT FUND, CANCER RESEARCH, ELECTION, FINANCE, HOUSE, LIBRARY, PUBLICATION, RESEARCH FUND, STANDARDIZATION, AND BRANCHES.

The President and the Honorary Secretary are ex-officio members of all Committees.

Members of the Awards Committee.

ALFRED C. ADAMS.
Prof. J. S. S. BRAME, C.B.E., F.I.C., F.C.S.
C. DALLEY, M.I.E.E.
T. DEWHURST, A.R.C.S., F.G.S.
ALEXANDER DUCKHAM, F.C.S.
A. E. DUNSTAN, D.Sc., F.I.C., F.C.S.
A. BEEBY THOMPSON, O.B.E., M.I.Mech.E., M.Inst.M.M., F.G.S.

Members of Benevolent Fund Committee.

ALFRED C. ADAMS.
ASHLEY CARTER, A.M.I.Mech.E.
ALEXANDER DUCKHAM, F.C.S.
A. E. DUNSTAN, D.Sc., F.I.C., F.C.S.
B. J. ELLIS.
T. R. H. GARRETT, M.A., F.G.S.
JOHN GILLESPIE, M.I.Mech.E.
Prof. V. C. ILLING.
J. MCCONNELL SANDERS, F.I.C., F.C.S.
A. WADE, D.Sc., A.R.C.S., F.G.S., M.Inst.M.M., F.Am.G.S.

Members of the Cancer Research Committee.

ALEXANDER DUCKHAM, F.C.S.
A. E. DUNSTAN, D.Sc., F.I.C., F.C.S.
F. H. GARNER, Ph.D., M.Sc., F.I.C.
Prof. A. W. NASH, M.Sc., F.C.S., M.I.Mech.E.
J. MCCONNELL SANDERS, F.I.C., F.C.S.
Dr. M. Y. YOUNG.

COMMITTEES.

Members of the Election Committee.

Lieut.-Col. S. J. M. Auld., O.B.E., M.C., D.Sc.
Ashley Carter, A.M.I.Mech.E.
A. E. Chambers, A.M.Inst.C.E.
G. H. Coxon.
C. Dalley, M.I.E.E.
T. Dewhurst, A.R.C.Sc., F.G.S.
B. J. Ellis.
F. H. Garner, Ph.D., M.Sc., F.I.C.
T. R. H. Garrett, M.A., F.G.S.
John Gillespie, M.I.Mech.E.
Prof. V. C. Illing.
F. B. Thole, D.Sc., F.I.C., F.C.S.
A. Beeby Thompson, O.B.E., M.I.Mech.E., M.Inst.M.M., F.G.S.

Members of the Finance Committee.

Alfred C. Adams.
Ashley Carter, A.M.I.Mech.E.
C. Dalley, M.I.E.E.
Alexander Duckham, F.C.S.
B. J. Ellis.
T. R. H. Garrett, M.A., F.G.S.
J. Gillespie, M.I.Mech.E.
J. McConnell Sanders, F.I.C., F.C.S.
A. Wade, D.Sc., A.R.C.S., F.G.S., M.Inst.M.M., F.Am.G.S.

Members of the House Committee.

Alfred C. Adams.
Ashley Carter, A.M.I.Mech.E.
Alexander Duckham, F.C.S.
B. J. Ellis.
T. R. H. Garrett, M.A., F.G.S.
J. Gillespie, M.I.Mech.E.
J. McConnell Sanders, F.I.C., F.C.S.
A. Wade, D.Sc., A.R.C.S., F.G.S., M.Inst.M.M., F.Am.G.S.

Members of the Publication Committee.

Lieut.-Col. S. J. M. Auld, O.B.E., M.C., D.Sc.
Ashley Carter, A.M.I.Mech.E.
A. E. Chambers, A.M.Inst.C.E.
G. H. Coxon.
C. Dalley, M.I.E.E.
T. Dewhurst, A.R.C.Sc., F.G.S.
A. E. Dunstan, D.Sc., F.I.C., F.C.S. (*Hon. Editor*).
B. J. Ellis.
F. H. Garner, Ph.D., M.Sc., F.I.C.
Prof. V. C. Illing.
J. S. Jackson, B.Sc., A.I.C.
J. McConnell Sanders, F.I.C., F.C.S.
George Sell (*Associate Editor*) (*ex officio*).
F. B. Thole, D.Sc., F.I.C., F.C.S.
A. Beeby Thompson, O.B.E., M.I.Mech.E., M.Inst.M.M., F.G.S.
A. Wade, D.Sc., A.R.C.S., F.G.S., M.Inst.M.M., F.Am.G.S.

Members of the Library Committee.

Prof. J. S. S. Brame, C.B.E., F.I.C., F.C.S.
T. Dewhurst, A.R.C.Sc., F.G.S.
B. J. Ellis.
J. Gillespie, M.I.Mech.E.
A. Wade, D.Sc., A.R.C.S., F.G.S., M.Inst.M.M., F.Am.G.S.

COMMITTEES.

Members of the Research Fund Committee.

ALFRED C. ADAMS.
Prof. J. S. S. BRAME, C.B.E., F.I.C., F.C.S.
A. E. DUNSTAN, D.Sc., F.I.C., F.C.S. (*ex officio*).
B. J. ELLIS.
F. H. GARNER, Ph.D., M.Sc., F.I.C.
J. GILLESPIE, M.I.Mech.E.
Prof. V. C. ILLING.
Prof. A. W. NASH, M.Sc., F.C.S., M.I.Mech.E.
J. MCCONNELL SANDERS, F.I.C., F.C.S.
F. B. THOLE, D.Sc., F.I.C., F.C.S.

Members of the Standardization Committee.

Prof. J. S. S. BRAME, C.B.E., F.I.C., F.C.S.
ALEXANDER DUCKHAM, F.C.S.
A. E. DUNSTAN, D.Sc., F.I.C., F.C.S.
F. H. GARNER, Ph.D., M.Sc., F.I.C.
J. E. HACKFORD, B.Sc., F.I.C., F.C.S.
JAMES KEWLEY, M.A., F.I.C., F.C.S.
J. MCCONNELL SANDERS, F.I.C., F.C.S.
P. E. SPIELMANN, Ph.D., F.I.C., B.Sc., A.R.C.S.
F. B. THOLE, D.Sc., F.I.C., F.C.S.
W. J. WILSON, F.I.C., A.C.G.I.

Members of the Persian Branch Committee.

E. C. BREWSTER (*Chairman*).
C. J. WRIGHT, B.A. (*Honorary Secretary and Treasurer*).
A. N. BAYLISS, B.Sc., A.M.I.Mech.E.
C. S. CLEVERLY.
ALEXANDER REID, B.Sc.
H. W. RIGDEN, B.Sc., A.I.C.
D. G. SMITH, A.R.C.S., B.Sc., A.I.C.

Members of the Rumanian Branch Committee.

Capt. J. E. TREACY (*Chairman*).
F. W. PENNY, B.Sc., F.G.S. (*Honorary Secretary and Treasurer*).
J. L. CHAILLET.
I. EDELEANU, A.C.G.I., B.Sc.
Capt. T. S. MASTERTON, D.S.O.
J. M. WALSH.

Members of the Trinidad Branch Committee.

A. FRANK DABELL, M.I.Mech.E. (*Chairman*).
H. W. REID (*Honorary Secretary and Treasurer*).
C. E. CAPITO, O.B.E.
W. J. C. COOKE, M.J.I.E.
J. L. HARRIS, B.Sc., A.R.C.Sc., A.R.S.M., A.M.Inst.M.M.
A. J. RUTHVEN-MURRAY, M.A., B.Sc., F.G.S.
G. H. SCOTT, B.Sc.

Members of the Welsh Branch Committee.

W. C. MITCHELL, B.Sc., A.C.G.I., M.Inst.C.E., M.I.Mech.E. (*Chairman*).
E. THORNTON, B.Sc., A.I.C. (*Honorary Secretary and Treasurer*).
T. D. AMBROSE, B.Sc.
E. J. HORLEY.
R. B. SOUTHALL.

CONTENTS.

PAGE

One Hundred and Thirty-Ninth General Meeting :—

The Geology of Zante and Its Ancient Oilfield, by ARTHUR WADE, D.Sc., A.R.C.Sc., F.G.S., M.Inst.M.M. 1

Discussion : The PRESIDENT, Prof. V. C. ILLING, T. DEWHURST, A. BEEBY THOMPSON, W. H. CADMAN, T. R. H. GARRETT, J. E. HACKFORD and W. G. WEEKS 28

Reply by Dr. A. WADE 33

The Crystallisation of Paraffin Wax. Part II., by E. KATZ.. 37

Oil Well Cementing. Effect of Mud Admixtures with Cement and Cement Grouts, by A. REID 53

Extinguishing and Controlling Fire on Bell and Graddy's No. 1 Daniels, Kilgore, Texas, by E. STANLEY DURWARD 57

Current Petroleum Notes : U.S.A. Asphalt Production .. 66

Reviews : " Oil Well Completion and Operation," by H. C. GEORGE ; " The Internal Combustion Engine," by D. R. PYE ; " Report of the Fuel Research Board for the Year Ended 31st March, 1931 " 67

The Journal of the Institution of Petroleum Technologists .. 73

One Hundred and Fortieth General Meeting :—

The Chemistry of the Conversion of Algæ into Bitumen and Petroleum and of the Fucosite-Petroleum Cycle, by J. E. HACKFORD, B.Sc., F.I.C. 74

Discussion : J. MCCONNELL SANDERS, Dr. A. WADE, Prof. A. W. NASH, Dr. P. HAAS, Dr. P. E. SPIELMANN and A. BEEBY THOMPSON 115

Reply by J. E. HACKFORD 122

Trinidad Branch :—

First Dinner 124

Lubrication Congress, Strasbourg, July 20th–26th, 1931, by A. GRAETZ 135

Reviews : " Lubricating Oil Tests and Their Significance," by J. E. SOUTHCOMBE ; " Index to A.S.T.M. Standards and Tentative Standards " 144

A New Physical Method for the Analysis of Gas Mixtures, especially those Consisting of Hydrocarbons, by Dr. W. J. D. VAN DYCK 145

CONTENTS.

PAGE

The Hydrogenation of Aromatic Hydrocarbons at High Pressure with Nickel on Kieselguhr as a Catalyst, by G. F. SCHOOREL, A. J. TULLENERS and H. I. WATERMAN 179

Influence of Tetraethyl Lead on Knock Rating, by L. E. HEBL and T. B. RENDEL 187

Cementation of Oil Wells with the Use of an Accelerator, by KOREPANOFF and MUCHINSKY 197

Reviews: "Deep Borehole Surveys and Problems," by M. H. HADDOCK; "Hydrierung, der Kohlen, Teere und Mineralöle," by Dr. ERNST GALLE; "Symposium on Effect of Temperature on the Properties of Metals," by A.S.T.M. and A.S.M.E.; "Chemistry at the Centenary (1931) Meeting of the British Association"; "Reports on Applied Chemistry, 1931," by Society of Chemical Industry 213

Annual Report of the Council, 1931–32 217

Nineteenth Annual General Meeting 226

Co-operation, by JAMES KEWLEY, M.A., F.I.C., F.C.S., M.I.Chem.E. 234

Reports on the Progress of Naphthology, 1930–1931 :—

Petroleum Geology, by JAMES ROMANES, F.G.S. 245

Oilfield Practice, by A. BEEBY THOMPSON, O.B.E., M.I.Mech.E., M.Inst.M.M., F.G.S., and ASHLEY CARTER, A.M.I.Mech.E. 250

Present Trends in Oil Pipe Lines, by R. P. BASCOM .. 256

American Refinery Technology, by BENJAMIN T. BROOKS, Ph.D., F.C.S. 260

Refining in Asia, by C. E. SPEARING, M.A., F.I.C., M.I.Chem.E. 269

Refining in Europe, by S. PILAT, Ph.D. 273

The Cracking Art in 1930–1931 by GUSTAV EGLOFF, Ph.D., M.A., M.Am.Inst.Chem.E., M.Am.Chem.Soc., BADONA L. LEVINSON and MARGARET HERRMAN .. 282

Distillation and Fractionation Equipment, by W. A. PETERS, B.A., B.S. 314

Gasoline and the Gasoline Engine, by O. THORNYCROFT and A. FERGUSON 329

Gum Formation and Its Inhibition in Motor Spirits, by W. H. THOMAS, A.R.S.M. 350

PAGE

Reports on the Progress of Naphthology—*continued.*

Kerosine and White Spirit, by WALTER A. WOODROW, A.I.C., F.C.S. 357

Lubricants, by E. A. EVANS, F.C.S. 362

Gas Oils, Diesel Fuels and Fuel Oils, by F. H. GARNER, Ph.D., M.Sc., F.I.C. 376

Oil Engines, by P. N. EVERETT, A.M.Inst.C.E. 383

Asphalts and Road Materials, by F. LEVY, A.I.C. .. 391

Special Products, by E. B. EVANS, M.Sc., A.I.C. .. 404

Benzole, by W. H. COLEMAN, F.I.C. 413

Low-Temperature Carbonisation and Low-Temperature Tar, by M. A. MATTHEWS, D.Sc., Ph.D., F.I.C. .. 415

Analysis and Testing, by A. W. COX, F.C.S. 420

Chemistry of Petroleum, By H. I. WATERMAN, A. J. TULLENERS and W. C. WEBBER, M.A. 429

Petroleum in the U.S.S.R., by GEORGE A. BURRELL, D.Sc., M.Am.Chem.Soc. 439

World's Production of Crude Petroleum, by GEORGE SELL 443

One Hundred and Forty-First General Meeting :—

Displacement Pumping as Applied to Oil Wells, by ALBERT MILLAR, A.M.I.Mech.E. 445

Discussion : The PRESIDENT, A. BEEBY THOMPSON, B. J. ELLIS, Dr. A. WADE, T. A. SMITH, Dr. J. A. L. HENDERSON, L. OWEN and CHARLES DABELL .. 477

Reply by C. A. ANDREWS 487

Contributed Discussion : ROBERT STIRLING, W. J. WIGNEY and C. DALLEY 487

Reply by ALBERT MILLAR 491

Trinidad Branch :—

Discussion on "Displacement Pumping as Applied to Oil Wells" : F. H. L. TINDALL, A. H. RICHARD, P. MEYER, J. W. HARDY, L. A. TOONE, J. P. POTTER, C. E., CAPITO, A. FRANK DABELL and C. R. MASSEY 502

Reply by ALBERT MILLAR 511

The Strobophonometer, by R. STANSFIELD, A.M.Inst.C.E., and R. E. H. CARPENTER 513

Influence of Tetraethyl Lead on Knock Rating. Contribution from Dr. F. B. THOLE and Mr. R. STANSFIELD 526

CONTENTS.

PAGE

Reviews : " Petroleum in the United States and Possessions," by RALPH ARNOLD and WILLIAM J. KEMNITZER ; " The Principles and Practice of Geophysical Prospecting, being the Report of the Imperial Geophysical Experimental Survey," edited by A. B. BROUGHTON EDGE and T. H. LABY ; " Das Erdöl seine Physik, Chemie, Geologie, Technologie und Sein Wirtschaftsbetreib, Part 1, Vol. III." edited by Dr. J. TAUSZ ; " The Scientific Principles of Petroleum Technology," by LEO GURWITSCH and HAROLD MOORE 527

One Hundred and Forty-Second General Meeting :—

Spontaneous Ignition Temperatures of Fuels, by F. A. FOORD, A.F.R.Ae.S. 533

Spontaneous Ignition Temperatures of Liquid Fuels and their Determination (German investigations), by J. L. CHALONER 548

Comparison of Spontaneous Ignition Temperatures and Starting and Ignition Delay Tests in Engines, by L. J. LE MESURIER, M.I.N.A., M.Inst.Mar.Eng. .. 562

Ignition Quality of Diesel Fuels, by J. J. BROEZE 569

Discussion : Dr. W. R. ORMANDY, R. STANSFIELD, C. B. DICKSEE, Squad-Leader W. HELMORE, Dr. W. J. D. VAN DYCK and W. A. TOOKEY 576

Contributed Discussion : A. K. BRUCE, J. KEWLEY, Dr. F. H. GARNER, Dr. D. SCHAFER and H. V. STEAD 585

Replies by F. A. FOORD, J. L. CHALONER and L. J. LE MESURIER 590

Progress in Hydrogenation of Petroleum during 1930 and 1931, by E. J. GOHR and R. P. RUSSELL 595

Flow in Pipes in the Critical Region, by E. S. L. BEALE and P. DOCKSEY, B.A. 607

Reviews : " Colloid Chemistry, Vols. III. and IV.," edited by JEROME ALEXANDER ; " Fuel Testing — Laboratory Methods in Fuel Technology," by G. W. HIMUS .. 626

One Hundred and Forty-Third General Meeting :—

Modern Oil Production Problems, by A. BEEBY THOMPSON, O.B.E., M.I.Mech.E., M.Inst.M.M., F.G.S. .. 629

Discussion : The PRESIDENT, Dr. A. WADE, ALBERT MILLAR, T. R. H. GARRETT, Dr. F. H. GARNER, C. DABELL, R. J. WARD and Capt. D. COMINS 668

PAGE

One Hundred and Forty-Third Meeting—*continued.*
Reply by A. Beeby Thompson 679

Contributed Discussion : S. H. Chapman, A. J. Goodman and C. E. Capito 682

Reply by A. Beeby Thompson 687

A Study of Energy in Relation to Production of Oil, by S. F. Shaw, M.Am.Inst.M. & M.E., Assoc.M.A.A.P.G.. 692

Progress in Rectification of the Light Petroleum Hydrocarbons, by S. C. Carney 701

The Determination of the Vapour Pressure of Gasoline according to the Method Used by the Bataafsche Petroleum Mij 716

A Selective Method of Acid Treatment for the Refining of Vapour Phase Cracked Distillates, by E. Retailliau .. 723

Reviews : "Chemical Encyclopædia," by C. T. Kingzett ; "Oil Economics," by Campbell Osborn ; "Handbook for Electric Welders" 729

Special Summer Meeting, 1932 733

Improved Methods of Examining Mineral Oils, Especially the High-Boiling Components of Non-Aromatic Character, by J. C. Vlugter, H. I. Waterman and H. A. Van Westen 735

The Knock Rating of Naphthene and Aromatic Hydrocarbons, by F. H. Garner, Ph.D., M.Sc., F.I.C. and E. B. Evans, M.Sc., A.I.C. 751

Note on the Geology of the Ionian Islands, by Arthur Wade, D.Sc., A.R.C.Sc. 779

Rumanian Branch :—
Production after Gas Lift, by L. W. Rogers 787

Discussion : Mr. Hoegenboezen, Mr. Chupp, Mr. Hodgson, G. Elias, Capt. J. E. Treacy, V. C. S. Georgescu and Mr. Auer 800

Reply by L. W. Rogers 841

Oil-Well Production-Curve Formulæ, by W. G. Weeks, A.R.S.M., A.R.C.S., F.G.S. 805

Reviews : "Tunnard's Tanker Tables," by B. Tunnard ; "Modern Coal-Cleaning Plant," by Sydney H. North.. 816

A Contribution to the Study of Oil-Field Water Analysis, by David Glynn Jones, B.Sc., and Charles Edmund Wood, M.Sc., A.I.C. 817

CONTENTS.

PAGE

Hydrogenation of Estonian Oil Shale and Shale Oil, by PAUL N. KOGERMAN, M.Sc., D.I.C., and JAAN KOPWILLEM, Ph.D., A.M.I.Chem.E. 833

The Recovery of Asphaltic Bitumens from Solutions as far as Possible without Altering their Properties, by J. GREUTERT 846

The Total Heat and Specific Heat of a Series of Fractions of Petroleum Oil, and Their Relation to Other Properties, by H. R. LANG, Ph.D., F.Inst.P. and R. JESSELL, B.Sc., A.Inst.P. 850

Experience with "C.I." Engines in L.G.O.C. Service, by A. A. M. DURRANT 866

Progress Report of International Studies on Nomenclature and Properties of Motor Fuels, by American National Committee, World Power Conference 874

Reviews: "Technical Data on Fuel," 3rd Edn., edited by H. M. SPIERS 885

One Hundred and Forty-Fourth General Meeting :—
Some Observations on the Study of an Oilfield, by J. W. WEIL, M.A., F.G.S. 881

Discussion : The PRESIDENT, Prof. V. C. ILLING, Mr. T. DEWHURST, Dr. A. WADE, Mr. T. R. H. GARRETT and Mr. A. BEEBY THOMPSON 890

Reply by J. W. WEIL 891

Presentation of Redwood Medal 898

The Refining Process with Liquid Sulphur Dioxide, by Dr. L. EDELEANU 900

Fourteenth Annual Dinner 921

An Analysis of Mineral Lubricating Oils by Fractionation with Acetone, by MILLICENT NOTTAGE B.Sc. 943

Rumanian Branch :—
Wire Rope Pumping, by P. R. CLARKE 953

Reviews: "Petroleum Development and Technology, 1932," by American Institute of Mining and Metallurgical Engineers; "Report of Committee D-2 on Petroleum Products and Lubricants," by American Society for Testing Materials; "Sands, Clays and Minerals," published by A. L. CURTIS; "The History of the Oil Engine," by A. F. EVANS 954

PAGE

The Physical Properties of Bitumen and Finely Divided Mineral Matter, by A. EVANS, A.R.C.S., B.Sc., D.I.C. .. 957

Cements and Well Cementing: Effect of Chlorides on the Setting and Hardening of Cement, by A. REID and J. T. EVANS, Ph.D., B.Sc. 992

Preparation of Paraffins from Carnuba Wax by Means of Catalytic Hydrogenation, by H. I. WATERMAN, P. DE KOK and A. J. TULLENERS 1007

Correspondence: Improved Methods of Examining Mineral Oils 1010

No. 99. Vol. 18.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE ONE HUNDRED AND THIRTY-NINTH GENERAL MEETING of the Institution of Petroleum Technologists was held at the Royal Society of Arts, John Street, Adelphi, on Tuesday, December 8th, 1931, Mr. J. Kewley, M.A., F.I.C., F.C.S., President, occupying the Chair.

The Secretary read the list of candidates nominated for election, and the following list of members elected :—

As Members.—Thomas Clarence Baker, J. A. Benkers, Samuel C. Carney, Leonard Hubert Cooper, Cedric Bernard Dickree, James Lonsdale Harris, Horace Cyril Benjamin Hickling, John Cyril Jennings, Howard Percy Jones, Earl Alphonso Kodyen, Albert Parsons Sachs, Cornelius Stribling Snodgrass, Francis Ernest Wellings, John Wilson.

As Transference to Members.—Bernard George Banks, Almon Lee Beall, Arthur Riley Bowen, Sydney John Fortescue, Charles Reginald Young.

As Associated Members.—Charles Arthur Andrews, David Robert Fyfe, William Hurst, Hugh Keith, Richard Nisbet, Frederick Reynolds Pacey, Douglas Redding, Geoffrey Sargent, Harry Woodfield.

As Transference to Associate Members.—Sydney William Cooke, Frederick George Fortescue, Percival George Higgs, John Macdonald, Daniel George Pidgeon, Cyril Bloomfield Roach, William Cyril Webber, Victor James Wilmoth.

As Students.—Standley Ernest Blackstone, Alan French, Walter Ronald Lewis, Alfred Wilson.

As Transfer to Student (from Associate).—Paul Pewsner.

The following paper was then read :—

The Geology of Zante and its Ancient Oilfield.

By ARTHUR WADE, D.Sc., A.R.C.Sc., F.G.S., M.Inst.M.M., etc. (Member).

I. INTRODUCTION.

IN its ancestry this paper goes back nearly 2500 years. Its subject has been touched upon by a long line of illustrious authors from Herodotus to our first President, Sir Boverton Redwood. Few of these writers seem to have paid more than a brief visit to

the Island, and though all are interested in its ancient occurrence of bitumen their studies in this direction are, for the most part, superficial. No adequate account of the geology of the Island, based upon palæontological determination, has yet been published, and such accounts as exist are conflicting and somewhat confusing. It is hoped that an orderly impression of the geological conditions existing on Zante will be conveyed by the present paper. In so far as it deals with the details of geological divisions and sequences it is provisional to some extent. This work must depend upon the determination and correlation of the fossil contents of the exposed strata. While the author has made extensive collections with this object in view, some time must elapse before such work is completed, and it is hoped that the results may be embodied in some future paper.

II. Historical.

The references made by Herodotus and Pliny to the occurrence of "pitch" on the Island of Zante have already been given in a paper published by this Institution[28] and need not be quoted again. Sir Boverton Redwood, in a brief visit to Zante, journeyed to the well which is, according to local tradition, the ancient well of Herodotus. The similarity of his description[26, p. 28] to that given by Herodotus is striking and shows that little change has taken place during the long intervening years. Greater change, in one respect, has taken place in the comparatively few years which have elapsed since his visit for, armed with one of the implements of twentieth century civilisation—dynamite—and a desire to increase production, some modern Greek destroyed the old pit without achieving his object.

Sir Boverton Redwood also refers to other occurrences of oil on Zante and criticises the conclusion arrived at by some earlier geologists, that the most important seepages occur in beds of Pliocene age, whereas he had formed the opinion that the beds are either Oligocene or early Miocene. That view is confirmed in the present paper[26, p. 136].

The Island is situated in a belt of intense seismic activity, and Issel,[23] who especially investigated the area from a seismic point of view, showed that a centre of disturbance from which seismic waves had passed along certain radiating lines was situated under the sea at no great distance to the S. Based on these seismic phenomena, some writers have put forward the thesis that the emanations of petroleum in Southern Zante were the result of vulcanism[25, 9, 10], and that the great semi-circular bay, a typical example of the results of depression and erosion, which characterises

the southern coast of the Island, was the outer rim of a submerged volcano.[25] The only evidence which exists in support of this is the fact that pieces of volcanic material are occasionally found on these shores. These, as Issel has already observed, are more likely to be waifs from the active volcanic areas which exist in the Mediterranean.

III. Topography.

Zante is the most southern of the Ionian Islands. It lies some 12 miles distant from the western coasts of the Morea, almost on the axis of the arc made by the Gulfs of Patras and Corinth. The

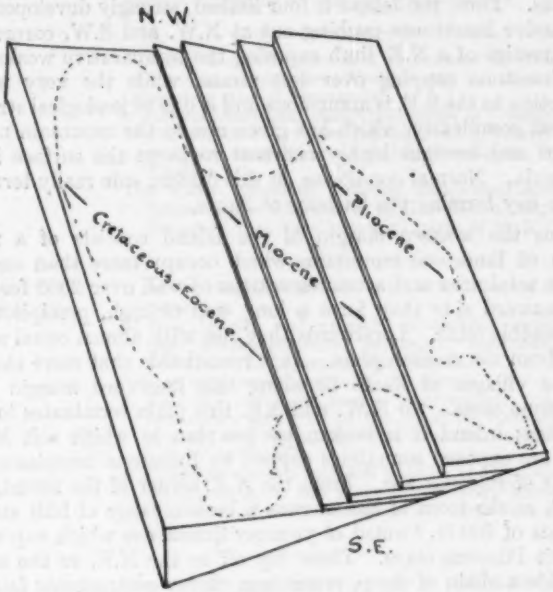


Fig. 1.
SIMPLIFIED STRUCTURAL DIAGRAM OF ZANTE.

long axis of the Island itself follows the Adriatic trend, *i.e.*, S.E.–N.W., which is normal in these Islands. It is 22 miles long, 10 miles in breadth, and covers an area of approximately 155 square miles. In general, the topography bears a simple relationship to the geological structure. The Island may be regarded as the

remnant of a rectangular block of resistant Cretaceous-Eocene limestone, orientated N.W.–S.E., tilted slightly to the N.E., and set in the Ionian Sea. Consider this to be neatly overlain by layers of soft Tertiary sediments (Miocene), marls, clays, gypsums and sands, which come in successively on the eastern slope, these sediments being protected by a capping of hard limestone of more recent origin (Pliocene) along the eastern margin. Thus we have a margin of hard rocks to the W., an eastern margin which is rather less hard and a weak and easily eroded series along the median line. Obviously the wide semi-circular bays which mark the emergence of these median strata at both N.W. and S.E. extremities are merely an expression of their presence and physical characteristics. Thus, the Island is four limbed, strongly developed arms of massive limestones pushing out at N.W. and S.W. corners, the mere vestige of a N.E. limb exposing the comparative weakness of the limestone capping over soft strata, while the very marked projection to the S.E. is anomalous and is due to geological structure of great complexity, which has given rise to the mountain mass of Skopos and brought highly resistant rocks to the surface in this peninsula. Normal conditions on this eastern side really terminate at the bay forming the harbour of Zante.

Thus the western margin of the Island consists of a rugged range of limestone mountains which occupy more than one-third of the total area and attain elevations of well over 2000 feet. On the seaward side they form a long wall of high, precipitous and inaccessible cliffs. Landwards they rise with almost equal abruptness from the median plain. It is remarkable that more than half of the villages of Zante lie along this landward margin of the limestone mass. To N.W. and S.E. this plain terminates in saline marshes; inland it is broken by low rises in which soft Miocene beds are exposed sometimes capped by limestone breccias and red earths of Pliocene age. From the N.E. corner of the island, as far South as the town of Zante, runs a broken range of hills attaining heights of 600 ft. formed of younger limestones which cap a series of soft Pliocene clays. These dip off to the N.E. to the sea and provide a chain of steep, crumbling, clayey escarpments facing W. and S.W. They terminate in the Citadel of Zante and are cut off by the bay which forms the town harbour. South of this bay a sudden change takes place. The prominent south-eastern limb of the Island is dominated by Mount Skopos and its spurs which fall away to the S. and extreme S.E. Skopos, though only about 1500 ft. in height, is a most impressive, isolated mountain mass, and is the most interesting feature in Zante in its topographic detail, its geology and from a scenic point of view.

IV. Geology.

1. *Stratigraphy.*

TABLE OF STRATA. (After Issel, much modified.)

Recent.	Downwash and detritus from the Pliocene hills along the eastern coast N. of the town of Zante and at the foot of the escarpments on the eastern side of the median plain.
	Dunes and beach sands both to the N. and S. of this plain and on the eastern coasts of the south-eastern peninsula.
Post-Pliocene.	Alluviums of the plain. Lignitic deposits of the Keri Marsh area. Red soils of Oxocora, Luca, Orthonies, etc.
	Ancient alluviums of Vasilico, Ipsolithos, etc.
Pliocene. 400-500 ft.	1. Shelly conglomerates and limestones of Geracarion, Kimaros, ridges above Vasilico, etc.
	Calcareous grits of Trentanovo.
	2. Concretionary and sandy limestones of Crionero, Cape Buveri, Batelli, Cape Kastelli, etc. Yellow, brown and blue clays of the Citadel, Geracarion, Tragachi, Vasilico, etc.
	The coarse limestone breccias and conglomerates of Lithakia, the Abyssos, S. of Keri Marsh, Lagopodon, Catastari, etc., may represent parts of both 1 and 2.
Miocene. 4,000 ft. ?	1. Sands, conglomerates and grits of Mt. Skopos, S. Lipio, Sarachina, etc.
	2. Fine banded and coarsely crystalline gypsums of Cape Sostis, Matheon, Sarachina, Ipsilithos, Xerocastellon. Alabasters of Mt. Skopos.
	Yellow clays associated with the above.
	3. Fine blue clays and flags with pteropods, passing up into sands and grits of the coastline between Capes Kastelli and Sostis, Lithakia, coast N. of Geracarion, hills W. of Tetapia.
	4. Bituminous marls with fish remains, chalky limestones, calcareous grits and clays of the Keri Marsh area, Lithakia and the foot hills of the limestone range to the N., etc.
Eocene.	Nummulitic limestones of the hills S. of Keri March, Keri Village, Lithakia, Pigadachia, Katastari. Black, bituminous limestone of Mt. Skopos.
Upper Cretaceous. (*Turonian*). 2,000 ft.+	Hippurite limestones of Keri, Maries, Luca, Oxocora S. Georgio, Orthonies, Volimes.
	Flinty limestone of Lagopodon.
	Spherulitic limestone of Mt. Skopos.
	Calcareous and flinty conglomerates of Mt. Skopos. ?

(*a*) *Cretaceous-Eocene.*—Geological maps of Zante show a broad belt of Cretaceous limestones occupying the whole of the western side of the Island from Cape Skinari, the most northerly point, to

the promontory which almost encircles the village of Keri in the extreme South. The eastern margin of this mass is almost a geographical straight line running S.E. Just N. of Keri Bay, however, the limestone wall turns abruptly due W. for about a mile, then turns equally sharply S. for about a mile and a half, turns again due E. and, finally, at Cape Marathia, takes up its normal direction and runs out to sea.

In this manner these limestone walls almost completely enclose a structural valley to the landward of Keri Bay. The floor of this valley is, in part, occupied by the marsh in which lies the pitch well of Herodotus. The gap eastward from Lithakia to the sea is filled by a ridge of limestone of Pliocene age which is, in places, almost indistinguishable, lithologically, from the older limestones over which it lies, a feature which has confused some of the earlier investigators.

The mountain range formed by the limestones which are termed Cretaceous-Eocene in this paper is steep and rugged, attaining elevations of over 2500 ft. The slopes and heights form large barren tracts, but good fertile soils are found where conditions are more favourable. The limestones themselves are hard and white or grey in colour. Occasionally they become earthy and, owing to hydration of ferrous impurities may locally be red in colour, drusy and rotten. In places they contain nodules of flint and marcasite, and finally, especially on the heights, they may show many different stages of secondary crystallisation and become true marbles in the northern part of the belt. Westward from the first steep rise from the median plain of the Island the limestones tend to form a dissected plateau, the surface of which is tilted westward towards the sea. On this plateau thin patches of red earth are present as near the villages of Volimos and Luca. This material is very similar to the ironstained fillings found in the pipes and fissures in the Chalk of southern England, and has originated in a similar manner. All the usual phenomena of limestone weathering are present.

Owing, perhaps, to the changes which these limestones have undergone, *e.g.*, recrystallisation, partial or complete, fossils are difficult to find, excepting in certain favourable localities, and even then they are usually badly preserved. Where fossils are present the limestones are often drusy owing to removal of parts by solution. The characteristic fossil of the western parts of the limestone belt is a species of the genus Hippurites (*Hippurites sulcatus*, Defrance, according to Issel). It is to be found in the outcrops near the lighthouse near to the S.W. extremity of the Island and in other localities along the whole of the western outcrop. The presence of this fossil correlates these beds with the Hippurite limestones of

the mainland and definitely assigns them to the Upper Cretaceous (Turonian) period. But the upper and more easterly parts of this limestone series must belong to a still later period, for, although there is no apparent break or change in physical characters, the limestones containing Hippurites pass upwards into a Nummulitic facies. Limestones consisting entirely of masses of well preserved Nummulities were found by the author on the mountain side forming the southern wall of the Keri Marsh depression and less well preserved specimens, which require very careful search to isolate, were found in places on the other margins of this depression right around to Lithakia and again near Pigadachia and Catastari much further North. Issel was, apparently, unable to find these Nummulitic beds, but he quotes Coquand[13] as having found these foraminifera near Lithakia, Fuchs[14] near Keri Bay (*N. lævigata*, Lam. and *N. lucasana*, Defrance), probably from the same locality as that examined by the author, Strickland[9] near Catastari, and Partsch[30] on the hill near Keri Village, where the village windmills stand at a height of about 900 ft. above sea level. Having quoted these authorities, however, he expresses the opinion that these occurrences are due to marginal fragments of a former Eocene cover which has been removed by denudation. This, however, is untenable, Issel, a very careful and accurate observer, being misled by not having observed the Nummulitic beds himself. From the neighbourhood of Keri Bay to Lithakia the passage upwards from Hippurite to Nummulitic limestone can be demonstrated, though it is impossible at present either to draw a dividing line or to say whether the Nummulitic zone is continuous along the whole eastern margin of the limestone outcrop. The occurrence of limestone with Nummulites on the windmill hill at Keri Village is probably an outlier of the upper beds lying on the flat limb of a monocline or asymetrical anticlinal fold in the limestones.

The core of Mount Scopos in the south-eastern promontory of Zante is formed of hard limestone beds, which constitute an impressive, pillar-like outcrop at the summit which, being almost white in colour, forms a landmark which can be seen for great distances in all directions. The rock forming the western part of the summit presents a remarkable appearance, being formed of almost perfect spheres of grey, white or pink limestone set in a hard calcareous matrix. These spherical bodies vary in size from small marbles to balls, which are two inches or more in diameter. There is little doubt that these are not rounded pebbles, but are more probably of organic origin, though they have not yet been microscopically examined for evidence of this. Associated with this "spherulitic limestone," as Issel terms it, are massive beds of compact, hard grey limestone standing out almost vertically from the summit.

A bed of dense black bituminous limestone appears to overlie this together with massive beds of calcareous conglomerate, containing boulders of limestone, together with pebbles of flint and chert. These limestones and associated beds come to the surface in the centre of a complex mass of deposits of Miocene age, conglomerates, sandstones, gypsums and alabasters and associated green clays. They are certainly older than these Miocene strata and are regarded as belonging to the Cretaceous-Eocene limestone group. No fossils have yet been determined in them, but attempts have been made to correlate the strata with beds present on the neighbouring mainland on lithological similarities. Microscopical examination may yet provide definite evidence of age, but on all other grounds it seems best to regard them as members of the limestone formation to which we have referred them.

(*b*) *Miocene.*—Overlying the massive limestones of the Cretaceous-Eocene group to the E. is a great series of deposits, very variable in character and usually soft and easily eroded. At certain horizons these beds are crowded with fossils, usually well preserved, a large number and variety of the smaller foraminifera being sometimes present. On the other hand, important parts of these deposits appear to be devoid of fossils. Little palæontological work has been done on this group, but such fossils as have been determined belong to species characteristic of the Miocene.

These Miocene deposits may be divided on lithological grounds into four sub-divisions :—

(1) A limestone-marl phase at the base followed by

(2) beds of fine blue clay with pteropods, interspersed with occasional beds of very fine grained, blue, calcareous flagstones, a few bands of limestone, then a gradual passage upwards into clayey sands and grey grits.

(3) Bedded and massive crystalline gypsums ;

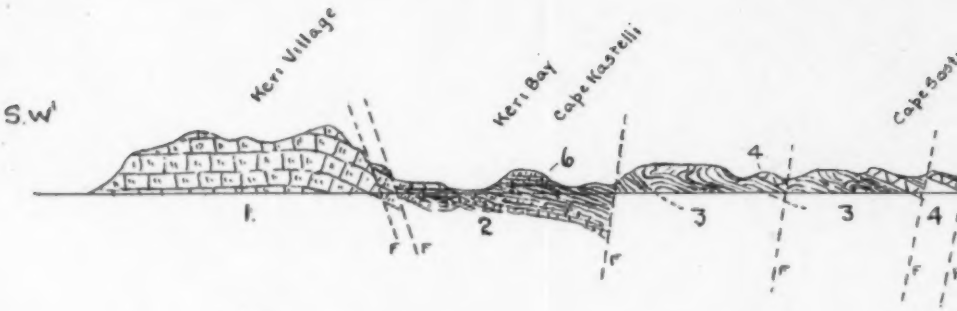
(4) sandstones, grits and conglomerates.

1. *The limestone-marl basement beds.*—The basement beds of this series consist of well-bedded and rather soft chalky limestones, which are massive and harder locally. Unless great care is taken they may appear to follow conformably in the Cretaceous-Eocene succession, a feature which has misled some earlier writers. These basal limestones are, however, distinctive in character and frequently contain fossiliferous material, not yet determined, which are believed to be the remains of calcareous algæ. The unconformable nature of the junction between the Cretaceous-Eocene and these later deposits is well defined at many places along the line of junction, especially in the coastal section exposed in Cape

Karavastasi, S. of Keri Bay, at the foot of the hills W. of Keri Bay and in the foothills to the N., especially near the village of Pigadachi. In the first named section, a black bituminous marly bed is to be seen resting on an eroded surface of hard Cretaceous-Eocene limestone wrapping around boulders of the latter which lie above it and filling in cracks and fissures, which were formed before the later period of deposition began. Associated with these bituminous basement beds are layers of coarse calcareous grits which indicate shallow water conditions. Near Pigadachia the unconformable nature of the junction is beautifully exposed and a good section of the lower Miocene sequence is revealed in a succession of white chalky limestones marls clays and soft calcareous sands. Higher beds in the Miocene sequence appear to be overlapping these lower members as we proceed N. where the blue clay of the higher division come into close proximity with the older limestone margin.

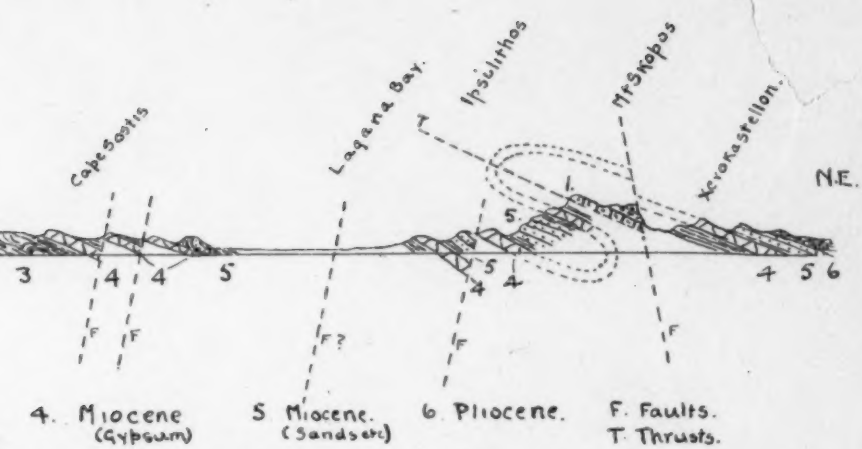
The lower Miocene strata are characterised by their marly nature and by the presence of bands which are impregnated with bituminous matter. To the S. side of Keri Bay and in the upper part of the ravine called the Abyssos, between the Bay and Lithakia, these beds are well exposed. Most worthy of attention are beds which outcrop in both localities, which are full of fish remains and fucoidal impressions. Fish scales, spines, teeth, jaws and even well preserved entire skeletons were found by the author, as well as a few specimens of the smaller foraminifera and other small fossils. These beds are dark in colour and bituminous. These lower Miocene strata are important as being the immediate "source rocks" of all oil which has been obtained by boring on Zante.

2. *The Blue Clay Series.*—As we pass upwards in the sequence the beds become more clayey and finally pass into a thick series of fine blue clays, which are first seen, in the southern coastal section, at the northern corner of Keri Bay, where they crop out on the sea shore from beneath a mass of calcareous sands, grits and limestones containing Pliocene fossils, and which lie in confusion caused by successive landslips from the cliffs behind. The underlying clays are the cause of these landslips, the relationship between them and the calcareous group above being similar to that between the Gault and the Chalk on the southern coasts of this country. Examination of the junction between the clays and these overlying strata shows well-marked unconformity and discordance of dip, the clays dipping N.E. at 30°, whereas the beds above are nearly horizontal. The coastal outcrop of the clays is often masked by debris and downwash from above, and to this is probably due the error into which some earlier writers have fallen in ascribing the deposits in which the petroleum occurs in the marsh to the S. to the Pliocene, an error to which Sir Boverton Redwood has already drawn attention.[26, p. 136]



1. Cretaceous-Eocene (Limestones) 2 Miocene (Marls) 3. Miocene (Clays) 4. Mioc (Gy

GEOLOGICAL SECTION ACROSS THE SOUTHERN

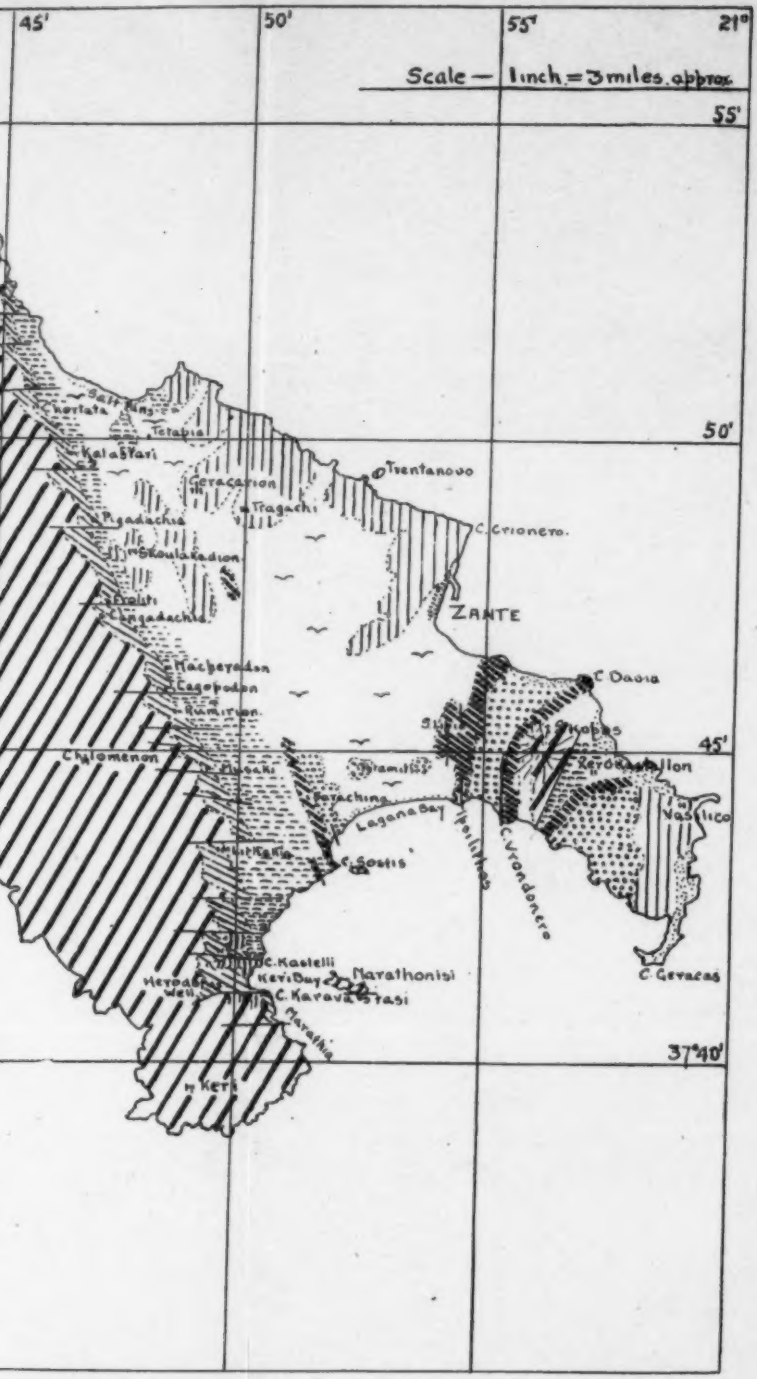


4. Miocene (Gypsum) 5 Miocene. (Sandstone) 6 Pliocene. F. Faults. T. Thrusts.

THE SOUTHERN PORTION OF ZANTE.

20° 40'
45'
C. Kinari
S. Giorgio
Orocopia
Vollimbo
Ortonies
Luca
Maries
Salt
Chortata
Kalab
Chytome
RECENT and POST PLIOCENE
Beach Sands
Alluvium.
PLIOCENE
Limestones etc.
Breccias.
Sands. Grits etc.
MIOCENE
Gypsum.
Clays etc.
Marls etc.
CRETACEOUS-EOCENE
Limestones
Faults.

GEOLOGICAL



GEOLOGICAL MAP OF ZANTE.

The correct relationship between the lower Miocene beds and the succeeding clays and of both to the overlying Pliocene is observable both in the coastal section and in the fine unbroken sequence exposed in the Abyssos as well as in many sections northwards through the Island.

The Blue Clay Series is best observed in the coastal cliffs to the N. of Cape Kastelli northwards of Keri Bay. Here the blue clays are very finely banded and occasionally contain small pebbles of limestone beautifully rounded and polished. Thin beds of hard blue flaggy limestone, from 2 to 8 in. thick, occur at intervals. This is a very smooth, fine-grained rock, very evenly bedded, and closely resembles the stones used by lithographers. As higher beds in the sequence are reached some clayey sands and coarse, black grits begin to appear, as well as one or two thicker beds of grey limestone 2 to 3 ft. in thickness. Finally, as we proceed northwards, a gradual transition takes place from dominating clays to dominating grey sands and grits and then, at a place called Matheon, a bed of coarsely crystalline gypsum, 30 ft. thick, pushes out to sea. This is apparently brought in by faulting, for another series of exposures of the clayey beds occurs before we reach the true base of the Gypsum Series.

The Blue Clay Series is fossiliferous in places and contains small foraminifera, echinoderms, squashed flat, and, in some parts of the sequence, numerous pteropods which have been referred by Coquand[13] to the species Cleodora and Hyalea. Coquand found these also inland near Lithakia and on the flanks of Mt. Skopos near the springs which feed the reservoir from which the town of Zante obtains its water supply. Minute crystals of gypsum were observed in places in the joints and along bedding planes in the clays. These may be secondary, carried down by percolating waters from the overlying Gypsum Series when it actually lay above these strata.

The Blue Clay Series underlies the greater part of the median plain of the Island, though exposures are rare, they being hidden under coverings of alluvium and transgressing Pliocene deposits. They outcrop and form low hills S. of the salt pans E. of Catastari, and are exposed in the sea cliffs N. of Geracarion, where they can be seen underlying a capping of calcareous and fossiliferous Pliocene deposits which lie unconformably above them. There are also some small local outcrops at the foot of the Pliocene escarpment near Geracarion.

3. *The Gypsum Series.*—The first appearance of the gypsum at Matheon has been noted. It is followed to the N. by blue, banded, flaggy clays with bands of pyritic limestone, which again pass upwards into soft, bedded sandstones and grits which appears

to be a duplication of part of the Blue Clay Series; but in this case we get a definite and unfaulted passage upwards into a gypseous series which attains its maximum development in the headland of Cape Sostis. At first sight the lower beds of the Gypsum Series look exactly like the siliceous sands and grits below. They consist of very finely banded layers of gypsum with black and brown partings. The gypsum is present in the form of small crystals, which were evidently deposited in very quiet conditions, so even is the bedding. Closely examined the beds look as though composed of sugar, and the fine banding in varying colours gives the outcrop a very striking appearance. The bands appear to be due to seasonal deposition, and call to mind the banding of "varve" clays. It is interesting to speculate as to the possibility of estimating the length of the period of deposition by making a count of the number of bands exposed in the section.

On the N. side of the headland a bed of coarsely crystalline gypsum comes in, similar to the one observed at Matheon. Some of the crystals are very large, running up to over a foot in length. The coast is low for about 200 yards N. of Cape Sostis, and then the banded gypsums come in again and are overlain by 6 ft. of grey, impure, coarsely crystalline gypsum, which is slickensided to the N.E. Above and below are beds of massive breccia, consisting of coarse broken fragments of crystalline gypsum, very impure, together with balls of greenish yellow clay. These breccias are associated with beds of a similar clay. This outcrop is another duplication due to the very evident faulting. There now follows a series of soft sand-stones, which are soon lost under the low sandy shores of Lagana Bay, and beneath the saline marsh which occupies the area between the bay and Zante.

The gypsums of Cape Sostis, especially the massive crystalline beds, outcrop as a broken succession of steep rises from Cape Sostis through Sarachina to a point one mile N. of the Keri-Zante road and about 2½ miles due E. of Rumirion. Here there are two parallel outcrops about 50 yards apart. N. of this they disappear under the alluvium of the plain, but were traced again in an exacavation from which gypsum was formerly quarried by the local peasants, at a spot about 1 mile S. of Geracarion. At this place they appear to be striking due N. towards the ridge of Geracarion where they are lost under the Pliocene escarpment.

Under Skopos, on the eastern margin of Lagana Bay, the gypsum series comes in again, the outcrops running right across the northern end of the south-eastern peninsula to the shores of the Bay of Zante. The series is repeated again and again in the Skopos mass both to N. and S. of the limestones forming the summit. It is here associated again with greenish-yellow clays as at Cape

Sostis, and is overlain by a succession of sandstones, grits and massive conglomerates which evidently belong to the upper part of the Miocene formation of the Island. Under the limestones of the summit a thick bed of pure white alabaster runs right across the mountain and forms distinctive white patches on the mountain when viewed from a distance. This duplication of the gypsum beds is due to complex and interesting geological structure which will be dealt with later.

4. *The sandstone group.*—Save for a few isolated outcrops of soft brown sandstone such as that overlying the Gypsum Series on the western side of Lagana Bay and inland near S. Lipio W. of the marshes and, less certainly, in the eastern portions of the median plain of the Island the sandstones, grits and conglomerates which belong to the upper part of the Miocene sequence and such an important part of the Skopos massif do not appear over the rest of the Island. They are probably buried beneath the Pliocene deposits to the E.

c. Pliocene.—The main feature of the Pliocene deposits of Zante is the broken range of hills running from the citadel of the town through the villages of Tragachi and Geracarion to the N.E. corner of the Island. These hills are the remnants of Pliocene deposits which must formerly have transgressed over the Miocene to the main limestone range to the W. These beds now present steep crumbling escarpments to the eastern side of the plain. The sequence in these scarps is grey or green fossiliferous clays at the base containing, amongst others, species of *Nassa*, *Venus*, *Cardium*, *Ostrea*, *Arca*, *Cerithium*, *Dentalium*. Small immature *Pectens* are especially abundant. Above are bands of hard fossiliferous limestone containing very large *Pectens* and, lastly, come calcareous grits, gravels and conglomerates often heavily charged with limonite. In the western flank of the hill N. of the winding road which leads up to Tragachi there outcrops a thick bed which is practically a shell bank composed entirely of species of the lamellibranch *Lucina*. Issel[23] refers the species to *L. pomum*, Dujardin and *L. globulous*, Deshayes, and considers that these indicate a Miocene age for the associated calcareous beds. Lucina, however, has a pretty wide range in Tertiary deposits, and, from an examination of the locality and the associated strata, this bed appears to be, undoubtedly, part of the Pliocene formation of these hills.

The Pliocene sequence as exposed in the hills at Geracarion and Tragachi is, perhaps, the most complete to be found on the Island. The limestones which outcrop W. of the road running along the foot of the escarpment towards the northern coast probably belong to the same formation which can be traced right across the plain to the main limestone range near Skoulakadion.

S. of Skopos clays, sands and calcareous grits are present in the ridge which constitutes the backbone of the south-eastern peninsula. The fossils present are almost identical with those found near Tragachi and Geracarion, but the limestone beds are not so important, there being a greater development of calcareous grits and sands in the vicinity of Vasilico. The island off the point of Sostis is composed of similar fossiliferous calcareous grits.

On the western side of the plain the Pliocene formation is represented chiefly by great banks of limestone breccias and conglomerates, which flank the main range and represent the work of the Pliocene seas pounding on the rocky shore line which the Cretaceous-Eocene limestones presented to them. These breccias and conglomerates are frequently held together by a red ferruginous cement, and weather into bright red soils which are particularly noticeable in the neighbourhood of Skoulakadion, where these beds attain, perhaps, their maximum development. They are also an important feature on the flanks of the Cretaceous-Eocene limestone mountains on the S. side of Keri Bay and round Cape Karavastasi, where they lie upon the marls and chalks of the basal Miocene.

N. of Keri Marsh and Bay is a limestone ridge which runs E. and W. and forms the headland of Kimaros and the cliffs of Cape Kastelli. This is capped by grey limestones, sometimes, apparently, devoid of fossils and closely resembling both the Cretaceous-Eocene limestones and those of the basal Miocene. In the broken cliffs of Cape Kastelli, however, they overlie calcareous grits and limestones containing large pectens and other fossils similar to those found in the limestones of Geracarion. Moreover, they lie almost horizontally above the Miocene blue clay series which is dipping at 30° to the N.E.

The ravine called the Abyssos is a cleft in the massive limestone breccias, which are here somewhat folded and faulted, and which can be traced eastwards into the limestones of Kimaros. The base is exposed in the ravine, showing the unconformable manner in which these beds overlie both the upper beds of the Miocene Marls and the lower beds of the blue clays, of which there is a very fine and continuous exposure in the floor of the ravine.

(*d*) *Quaternary and recent.*—Little need be said of the recent formations which consist of alluviums, the downwash from the crumbling shales of the eastern Pliocene escarpments, the red earths due to weathering of the various limestone deposits from the Cretaceous to the Pliocene, raised pebble banks which occur in places, especially on the N. side of Skopus at about 100 ft. above sea-level, and which can be seen in the neighbourhood of the Vasilico Road. Such deposits are of little importance geologically, though they do contribute to the fertility of the Island in places.

(*e*) *Correlation.*—In the absence of adequate palæontological work the author has, as yet, made no serious attempt to correlate the strata as exposed on the Island of Zante with those of neighbouring lands. From the Cretaceous-Eocene limestones upwards the sequence and types of strata are closely related to those found in the Morea and northwards, through Greece into Albania. The spread of the Hippurite and Nummulitic limestones in Europe and Asia is well known. Gypseous series of Miocene age occur elsewhere in Greece, in Cyprus, and in the northern areas around the Red Sea. The marly and chalky limestones of the Lower Miocene may be linked with the Globigerina limestones of Malta, which seem to occur at about the same horizon.[24]

2. *Structure.*—A section across the Island anywhere N. of the Bay of Zante would show an apparently simple structure and sequence across most of the strata described. We should find, however, that our simple conception of the Island as a rectangular limestone block overlain by later sediments would have to be modified, and that there had been some deformation owing to folding movements. The belt of Cretaceous-Eocene limestones of the western margin is folded into a great assymetrical anticline which is almost monoclinal in places as near Keri Village. The dips are low to the westward. To the E. and N.E. the dips amount to from 30° to 45°. The overlying Miocene deposits also have a general dip to the N.E., the average angle of dip being about 25°. With regard to the Pliocene deposits of the hills to the N. and E. of the town of Zante the dip is perhaps a little more N.N.E. and varies between 10° and 15°.

A section across the Island in the latitude of Mount Skopos would reveal a much more complicated structure; in fact, no serious attempt appears to have been made previously to unravel it, especially that of Skopos itself. If a line be taken from the western coast near the lighthouse near the S.W. corner of the Island, across the Keri Marsh and along the cliffs of the south-eastern coasts, its continuation would pass through the centre of the Skopos mass. Near the lighthouse the beds dip at very low angles to the S.W. Inland, near Keri Village, there is evidence of unimportant local faulting and folding in the limestone. As we approach the southern edge of the Keri Marsh the massive limestones dip E. at from 20° to 30°, and a series of important E. and W. faults, with downthrow to the N., begin to come in and culminate in a fault with a downthrow to the N. of some magnitude, heading N. at 60° to 70°. Against this fault the Lower Miocene marls and limestones abut in places, though in others Eocene limestone, full of Nummulites, were observed both above and below the fault zone. The slickensided, grooved and polished

face of the fault is exposed on the northern side of Cape Karavastasi, where the fault runs out to sea, and against this face the lower beds of the Miocene are resting A continuation of this fault appears to cut across the southern end of the Island of Marathonisi, some two miles to the E. There is little doubt that this fault is still "alive," and that movement has taken place along it in comparatively recent times in connection with the numerous earthquakes to which Zante is subject. Associated with the emergence of this fault on the coast springs of sulphuretted water occur along the rocky coast known as the Marathia, and associated with these occasional seeps of petroleum have been observed coming from the sea floor. At times a distinct odour of petroleum is to be observed along this part of the coast.

The Miocene deposits S. of the Marsh dip N.E. at low angles; on the coast at 5° to 8°, inland to the westwards at 12° to the N.E. On the northern side of the Marsh the Miocene marls again appear N. of the Herodotus Well dipping N.E. at 5° to 10° under the Pliocene ridge already described. The Pliocene strata forming the ridge have been affected somewhat by earth movements and are slightly folded along a N.W.-S.E. axis. The blue clay series makes its first appearance under the Pliocene sea cliffs dipping N.E. at 15° to 30°. It is only when we get to the clear, unbroken exposure of these Miocene clays in the coastal cliffs to the N.E. of the headland of Kimaros that we get any idea of the structural movements which have affected the Miocene deposits. The clays and overlying sands are here intensely contorted, overthrusting and overfolding of a diagrammatic kind being present, while normal faults also affect the strata. The forces which have brought about the compression of the strata have been applied from the N.E., *i.e.*, from the direction of Mount Skopos. We have seen that after the first appearance of massive gypsum at Matheon, where it is brought in by a fault, the Blue Clay sequence is duplicated by faulting. The overlying Gypsum Series, as is evident from the broken nature of the outcrops which run northwards from Matheon and Cape Sostis through Sarachina, has yielded to the pressure by breaking into rectangular blocks, fracturing rather than folding, the blocks being pushed forward in an irregular manner. At Cape Sostis the Gypsums dip N.E. at 20°. The gypsum breccias 200 yards N. of Cape Sostis are connected with another fault zone, which brings the crystalline gypsum to the surface again at this point. The fault here strikes 20° W. of N. retain hades to the N.E. A fault plane running exactly parallel to this is seen in the sandstone outcrop to the E. of this.

At Ipsilithos (ipse=gypsum), at the eastern end of Lagana Bay, the Gypsum Series, associated with greenish clays and sandstones,

comes in again dipping 65° N.E. and striking 20° W. of N. The exposed thickness of gypsum beds is here over 300 ft., 400 yards to the E. the whole series comes in again, striking 15° W. of N. and dipping 15° N. of E. at 45°. Overlying this outcrop is a massive sandstone series dipping 78° to the E. and striking 10° W. of N. A thickness of 200 ft. is exposed. These two outcrops of the Gypsum Series form ridges which run brokenly across the N. end of the south-eastern peninsula of Zante to the southern coast of the Bay of Zante. The faulted and disturbed nature of the beds is again expressed in the irregular character of these outcrops. Still further W. the Gypsums come in a third time and constitute the headland of Cape Vrondonero. The western side of this headland is a vertical vault face running N. and S. It is lined by a fault breccia consisting of large angular blocks of crystalline gypsum. The Gypsums of Cape Vrondonero run N. up the western flanks of Mount Skopos, forming a marked platform on its slopes. A little way inland the strike changes to N.E. dip, S.E. 40°. They cross the mountain just under the summit and pass out to sea in Cape Davia. In this particular occurrence of the Gypsum Series the material has been altered to a white alabaster which sometimes contains carbonaceous matter as an impurity. Under the summit the bed appears to be dipping E. at a high angle.

The limestones and conglomerates which have been described as occupying the summit of Skopos are traversed by an important series of faults which apparently belong to two periods. One group runs N. and S., and the other between E. and W., and N.E. and S.W. The N. and S. faults are probably of the nature of thrusts which have forced the Cretaceous-Eocene succession over the Miocene gypsums and arenaceous beds. The E. and W. faults are normal. They must be of later age, for they cut across and terminate the N. and S. faults. The junction between the limestones of the summit and the associated conglomerates is a N. and S. fault plane (10° W. of N.), and is occupied by a fault breccia. In connexion with these fault breccias pebbles occur, which are crushed, fractured and distorted, and yet remain entire. A mile or so to the S.E. of the summit the whole series is cut off sharply by a fault running N.E.-S.W. with downthrow to the S.E. The fault plane is a precipice some hundreds of feet sheer and runs right across the peninsula. This fault is again normal.

Dropping down from the heights of the precipice in the direction of Vasilico to the S.E. we find the whole Gypsum Series and some of the lower members of the Miocene coming in again at Xerocastellon. The gypsum outcrop crosses the peninsula again, striking here nearly E. and W. and dipping S., but there is again some disturbance by faulting. Miocene beds occur in the ridges

towards Vasilico, where they are are at last hidden beneath the Pliocene deposits.

Consideration of the section thus described gives us a good idea of the general structure of the southern part of the Island and, to some extent by inference of the whole of it. Starting with the most important geological structure, that of the Skopos mass, it can now be interpreted as an eroded and faulted S-shaped overfold in the Miocene gypsums the beds rising from Xerocastellon folding back under the summit of Skopos and coming up again at Ipsilithos. The Cretaceous-Eocene limestones and conglomerates are exposed and have probably been extruded in the core of the anticlinal part of the overfold which forms the heights of Skopos. In the accompanying syncline westwards towards Ipsilithos is a great mass of the sandstones, grits and conglomerates which overlie the gypsum, but of which little is seen over the rest of the Island. Because of the position of these beds in the axis of the syncline and duplication by the folding their apparent thickness and importance is exaggerated on the western flanks of the mountain. Both to N. and S. the complete fold is cut off by faults, to the N. the fault noted in the precipices of Cape Vrondonero ; to the S. the fault forming the precipice above Xerocastellon.

Following upon this to the westward is a whole series of step faults, throwing down the gypseous group to the W. First, one of comparatively small magnitude duplicating the gypsum outcrops at Ipsolithos, then a larger fault or a series of smaller ones which are hidden under the beach formations of Lagana Bay and the marsh to the N. of it which bring in the Gypsums again at the western end of the Bay, finally, a third group of such faults, still throwing down to the W. which bring up these Gypsums at least four times, the last being at Matheon and cause the Blue Clay group to appear twice in the coastal section. It has been noted that normal faults occur in the main section of the Blue Clay group N. of Cape Kastelli, and there is undoubtedly some duplication here also, but the crumpling of these strata rather obscures matters and makes it difficult to unravel the true sequence until it can be done on palæontological grounds. Wherever they can be observed these step faults run from 10° to 20° W. of N., are almost vertical or hade at high angles to the S.

The great fault on the margin of the limestone range S. of Keri Marsh runs E. and W., but hades to the N. at 60° to 70° so that in effect the structure between Ipsolithos and the limestone Range is that of a trough fault, which affects both the Cretaceous-Eocene limestones and the whole of the overlying Miocene. The soft Miocene strata have been dropped into this trough and, being compelled to shorten their surface dimensions, have been crumpled

and contorted. The jaws of the vice are provided by the Cretaceous-Eocene blocks of Skopos to the E. and the Limestone range to the W.

The author believes that the structure of the whole of the median plain of the Island is a faulted trough of this description, though the scarity of outcrops make it difficult to prove. There is, however, a great change in the Island S. of the latitude of the Town of Zante. This southern part of the Island seems to have been greatly affected by pressure from the eastwards producing not only the overfolding and thrusting of Skopos, but effects which can be noted right across to the limestone range in the neighbourhood of the Keri Marsh. The clayey beds in the coastal exposures have been urged forward, overthrust and tilted, the movements being invariably directed towards the W. or S.W. In the higher parts of these folds and contortions the strata always show a tendency to be bent backwards on themselves in the opposite direction as though they were meeting with some obstruction. This resistance was provided by the Cretaceous-Eocene limestone block against which they were being jammed. But these limestones themselves have yielded to the forces at work and have broken before them. The curious, abrupt changes in direction which take place in the limestone wall which confines the Keri Bay and Marsh area are due to the main limestone mass having been fractured and pushed forward to the W. for at least one mile. The tangential thrust movement which produced this Keri Bay re-entrant and the folding of Skopos, also fractured the whole of the Cretaceous-Eocene limestone block. Passing from N. to S. down the landward side of the limestone range we find that it is broken at almost regular intervals by a series of E. and W. dip faults which are normal and, with the one exception of the fault S. of the Keri Marsh, throw down to the S. They cut across the strike of the limestones almost at right angles and their effect is to cause the limestone margin to be stepped back regularly and progressivelty towards the W. In other words, the limestone has bent before the forces at work, the bending strain being relieved by a series of comparatively small fractures, which are the faults described. The result is like the jointing of a vertebral column.

With the possible exception of the E. and W. fault S. of Keri Bay this faulting is younger than the Miocene of Zante, for even the youngest beds of this system which are present are affected. The movements must have taken place before the Pliocene deposits of the Island were laid down, for these are not affected by them, though the slight tilting and folding which are observable in these beds show that pressure from the E. continued right through Pliocene times into more recent eras and has probably not died away even yet.

3. *History.*—The Cretaceous-Eocene limestones had been uplifted and eroded before the Miocene deposits were laid down, but were evidently back beneath the sea again at this time, probably forming a reef. The basal beds of the Miocene contain calcareous grits associated with limestones formed largely from calcareous algæ, which suggest shallow marine conditions. The contrast between these and the basal breccias and conglomerates of the Pliocene is striking.

Depression followed, attaining its maximum when the fine blue clays with pteropods were laid down. Gradual shallowing of the sea is shown by the coming in of the grits and sands which finally dominate the upper beds of the blue clay series. Apparently isolation and inland sea conditions existed when the gypsums were laid down. Further uplift followed, together with encroachment of neighbouring land areas when the sands, grits and conglomerates of the upper part of the Miocene sequence were formed. By this time the Cretaceous-Eocene limestones were being elevated, and by Pliocene times formed part of a land area to the W., and against the limestone coasts so formed Pliocene seas beat with some violence, tearing away huge blocks to form the breccias and conglomerates of that formation. Shallow marine conditions existed throughout the period. Evidence round the coasts of Zante and of Greece itself indicates that recent movements have been in the direction of submergence again, and the earthquakes of recent times may represent repercussions of the forces which have been at work on the Island since the Cretaceous period.

V. Petroleum.

1. *Description of oilfield area.*—The so-called "pitch" of Zante is really a very heavy crude oil, the physical and chemical characteristics of which will be dealt with later.

The ancient "pitch" well of Herodotus is situated on the S. side of the Keri Marsh, almost exactly 400 yards from the shore, whereas Herodotus says it is distant from the sea, four furlongs or about 655 yards, according to authorities on the measures in use in that author's time. This is interesting as giving some idea of the retrocession of the coastline of Keri Bay during the past 2500 years. The well is a natural spring of slightly brackish water, which energes almost at the junction between the Lower Miocene and the underlying older limestones. The fact that inflammable gas and oil accompanies the flow of water has led to many efforts, stimulated by the successful rise of the oil industry in the U.S.A., to obtain larger supplies of oil during the past sixty or seventy years. Most of those who have written on Zante refer to the comparative failure of these efforts. At the time of Issel's visit (1893) the work

seems to have been abandoned for the time being, but he refers to two wells which had been drilled near the ancient spring,[23] and says that one produced half a ton of oil a day from an oil horizon at 48 metres, and was continued to 150 metres without, apparently, increasing production. The other found oil at 21 metres and yielded 2½ tons in a few hours after which it seems to have become exhausted. Both wells were said to have been drilled in blue clays, and Issel is uncertain as to whether these were Miocene or Pliocene. Sir Boverton Redwood also states that these attempts have all proved futile[26, p. 28], giving his opinion that this is due to the prevalence of earthquakes and the shattering of the limestones in which the oil originally existed. He states, however, that the beds in which the oil occurs are either Miocene or even Oligocene. Having, with the manager in charge of the work now in progress on the Island, found it necessary to make a survey of these old wells, of which 10 or 12 were found scattered over and around the Keri Marsh, the author finds that the failure of the work was more probably due to lack of knowledge and inexperience of oilfield practice on the part of the early operators. In no case was water shut off, not even the surface water of the marsh in most cases. The casing of the wells was faulty and inadequate. Casing seemed to consist of job lots of all descriptions, one set being of a kind never before seen by the author. It was collar casing with the collar couplings on the inside of the pipe instead of outside, which made it almost impossible to run tools or even to insert sucker rods for trial pumping. Before the present work could be undertaken it was necessary to make a thorough, and what proved to be a difficult, search for these old wells, to open them up, examine and test them, and in all cases it was found necessary to clear the bottom and to force in cement under pressure. In many cases cementing was necessary from top to bottom. That having been done it has been found possible to produce oil free from water from well newly drilled on other sites.

Besides the seepage in the Herodotus Well there are other occurrences of oil in the Keri Marsh. One rather extensive seepage is present just within the northern margin of the Marsh N. of the well. The seepages of oil which occur in the sea off the faulted coastline of the Marathia have been already noted[23 & 26, p. 136]. Redwood states that temporary discharges of pitch and oil have occurred from fissures produced by earthquakes near the villages of Musaki and Rumirion N. of Lithakia[26, p. 135]. His authority is probably one of Mercati's old manuscripts,[4] for Mercati states that at Rumirion this occurred in 1831. In both these cases the horizon is the basal beds of the Miocene as in the Keri Marsh. Redwood also says that exudations of petroleum were observed by him on the seashore N.E. of and near to the town of Zante in beds of

Pliocene age. It may be observed, however, that the Miocene beds underlie this formation at no great depth in this locality. Both Redwood and Issel refer to rocks smelling of petroleum in the Miocene strata of Mount Skopos, Issel giving his locality as the cliffs of Vrondonero.[23] The author is able to confirm this from personal experience.

Springs of sulphuretted water occur, both in close connection with the known oil-bearing strata and at other points on the Island. One occurs in an outcrop of bituminous marl on the beach at the S.E. corner of Keri Bay about 100 yards S. of one of the most productive of the older oil wells. It is associated with a small fault in the beds. A trial bore 100 yards due W. of this old well met with water similarly charged. Similar springs of sulphur-charged water have been observed by the author at Musachi, where the occurrence is associated with a smell of petroleum and an occasional discharge of oil[26, p. 135 & 23], near Catastari and Pigadachia to the N., all on the basal Miocene, and at Tetapia between Geracarion and the salt pans on the N.E. coast at the northern end of the median plain and in a vineyard S. of the farm-house at this place. In this case the spring breaks through alluvium which is covering Miocene beds.

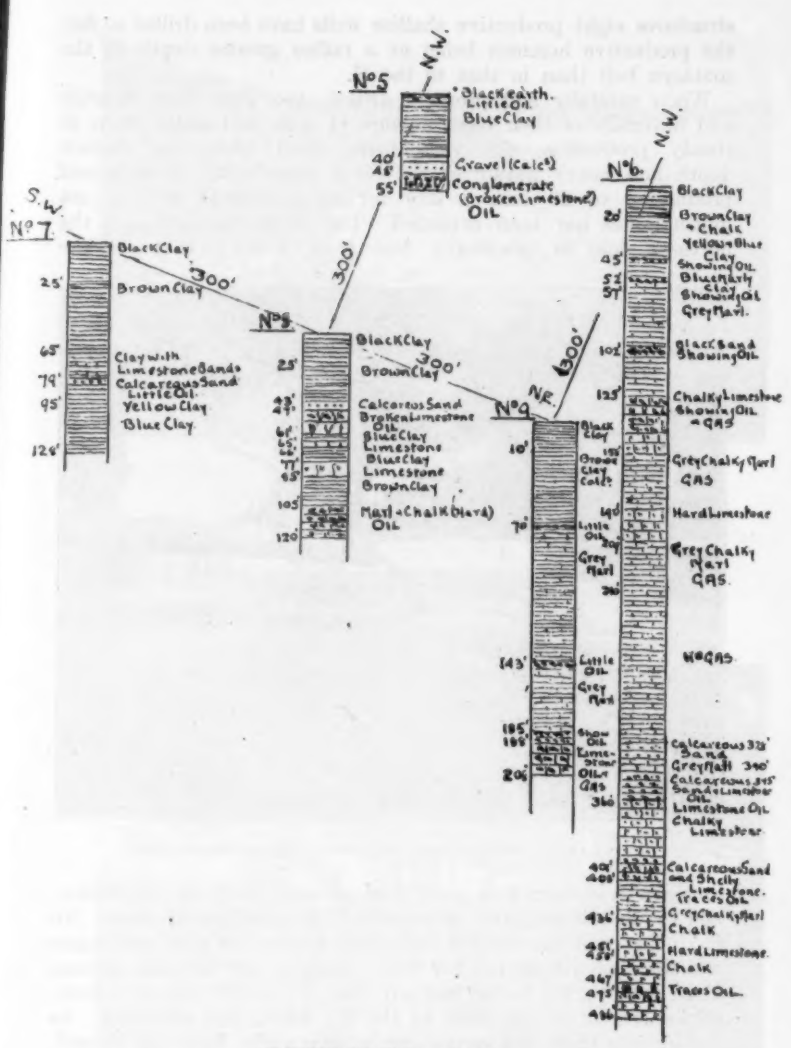
No attempt to find oil has been made excepting in the area around and in the Keri Marsh, and here it is present in porous, calcareous grits in the basal Miocene.

In a general way the structure of the Keri Marsh area is a "terrace." The marls and limestones underlying the area dip at low angles, 5° to 10°, to the N.E., abut against the wall of older limestones which limit the area to the S. and rest upon an irregular, eroded and, probably, faulted surface of the same rocks. Immediately to the N., under the headland of Kimaros, the dip steepens to 30° and even more, and, if we ignore the effects of the thrust movements, continues at about this angle for at least 8 or 10 miles. The Miocene strata are, therefore, rising at a fairly steep angle for a considerable distance from the N.E., and this rise is sharply arrested where the lowest beds come to the surface in the Keri Marsh area. This set of conditions is sufficient to account for any accumulation of petroleum which may occur in this area. The basal Miocene cover in the Marsh area is only a few hundred feet thick, therefore, so far as oil in the Miocene formation is concerned, the field is a shallow one. But the structure is not quite so simple as this. We have noted how in two boreholes near the Herodotus Well, only a few yards apart, one met with oil at 48 metres and the other at 21 metres. This is typical of all the bores which have been put down. It is reasonable to suppose that the faulting which Sir Boverton Redwood had in mind when referring to the

field was of the normal type. Careful study of the exposures of Miocene to the northward, and especially of those nearest to the marsh, leads to the conclusion that faults and folds should occur in the Miocene beds under the marsh area. The logs of the older wells are not reliable, but those of the more recent ones have been carefully recorded and kept, and a study of these indicates that we have under the marsh a series of overthrust folds whose long axes run some degrees to the W. of N. or parallel to the direction noted wherever the thrust faults in the Miocene can be observed. It is certain that general elevation of both Cretaceous-Eocene beds and the Miocene had taken place before the onset of the earth movements, which probably occurred in early Pliocene times, caused the crumpling and thrusting of the beds, and it is obvious that any migration of oil towards the higher points of elevation must have taken place before complication due to the later movements in the strata had taken place, for such structures as are present would certainly have made migration of oil impossible. In such conditions any general accumulation of oil which may have taken place in this area when the terrace structure was formed would be compelled to accommodate itself to the later conditions which were imposed upon it. Some of it would probably escape to the surface along fracture zones in the marls, chalks and calcareous grits owing to disturbance of the clays which formed the effective cover. Other bodies of oil would be saved in local folds in which both storage and cover beds were involved. This reading of the structure fits very well with the facts as disclosed by drilling. The appended sections give an idea of the anomalous conditions which exist.

Sections.

The anomalies disclosed in these sections may be accounted for by normal faulting if we assume the presence of faults running N.-S. There is no evidence of the existence of such faults. Normal folding will not explain them. Small lenses of porous beds can also be made to account for the way in which the "oil sands" occur, but again nothing has been observed to suggest that such small lenses are present, though a similar effect would be produced by such disposition of the strata as is observable in the small overthrust folds which do exist to the N., and this is the solution of the problem which seems most in accordance with observable structural conditions. Two such areas of productive folding have been disclosed by drilling. The first is that to which the above sections apply, and is just within the northern margin of the marsh. The second runs from the coast just outside the southern margin towards, but a little to the N. of, the Herodotus Well. On these



SECTIONS OF BORE HOLES.

structures eight productive shallow wells have been drilled so far, the productive horizons being at a rather greater depth in the southern belt than in that to the N.

When carefully and properly drilled, the wells flow steadily and naturally of their own pressure at first, and settle down to steady production, the yield being good when the shallow depth and heavy nature of the oil is considered. A measured production of 20 tons a day for an individual well is not unusual, and has been exceeded. The oil in the wells on the northern fold is practically free from water; that on the

KERI MARSH. OIL FLOWING FROM WELL INTO SETTLING TANK.

southern fold carries a good deal of salt water in suspension, and the flow is normally accompanied by quantities of brine. No producing well has become exhausted during the past four years and the pressures are holding well. There is very little gas present along with the oil in the southern fold, but a fair amount accompanies the oil in the wells to the N., which was expected. As the sections show, the productive horizon varies from well to well, though the same horizon may be oil bearing in many wells though not to a commercial extent. This, again, is to be expected in such structural conditions.

VIEW FROM LIMESTONE RANGE SOUTH OF KERI BAY LOOKING NORTH-EAST ALONG COASTAL SECTION.

Foreground.—Miocene Marls and Chalky Limestones, Keri Marsh Oilfield Area.
Middle Distance.—Pliocene Limestones and Cretaceous Sands overlying Miocene Blue Clays on Cape Kastelli.
Background.—Coastal Cliffs exposing Miocene Blue Clays sequence.
Distance.—Pliocene of Citadel Hill overlooking town of Zante.

SITE OF HERODOTUS WELL.

BITUMINOUS BASAL MARLS OF MIOCENE SOUTH OF KERI BAY.

OVERTHRUSTING AND FOLDING IN BLUE CLAY SERIES. COASTAL SECTION NORTH OF CAPE KASTELLI.

MIOCENE. OUTCROPS OF COARSE CRYSTALLINE GYPSUM INLAND NORTH OF CAPE SOSTIS.

MIOCENE. FOLDING IN SANDSTONES OVERLYING GYPSUM NORTH-WEST OF CAPE SOSTIS.

MOUNT SKOPOS, FROM TOWN OF ZANTE.

Projection on Summit.—Cretaceous-Eocene Limestone.
White patch under Summit.—Miocene Gypsum (Alabaster).
Hills in foreground of Mountain.—Miocene Gypsum duplicated by faults and folding

OIL WELL AND PIPE-LINE, KERI MARSH.

2. *Characteristics of the oil.*—Examination of two samples of the oil gave the following results :—

	No. 1* Southern Fold.	No. 2† Northern Fold.
Specific Gravity at 60° F.	1·010	1·0046
Closed Flash Point (P.M.)	156° F.	200° F.
Viscosity (R.I. at 140° F.)	—	690 secs.
Water Content (I.P.T. method) ..	0·8%	—
Initial Boiling Point	—	150° C.
Petrol	0·7%	1·0%
Kerosene (150°–300°)	14·4%	14·0%
Specific Gravity at 60° F.	0·8625	0·8795
Lubricating Oil	33%	43%
Specific Gravity at 60° F.	0·917	0·9313
Asphalt	51·1%	42%
Specific Gravity at 60° F.	1·092	1·1182
Asphaltum		24·2%
Asphaltenes		5·86%
Sulphur		6·01%
Ash		0·31%

* Esling. † Hackford.

3. *Origin of the oil.*—There seems to be no good reason why one should seek further than the strata with which the oil is actually associated for its source of origin. Attention has been drawn to the beds of marl which occur in the lower strata of the Miocene which are full of organic matter and distinctly bituminous. Fucoids have left in them abundant traces, and these are associated with masses of fish remains as well as other organisms. We have also noted that, in the cliffs of the Marathia, the lowest bed of the Miocene is black and bituminous where it rests unconformably on a floor of Cretaceous-Eocene limestones. The variations in the strata of this group of beds is such as to be almost ideal from an oilfield point of view. Porous calcareous grits occur in association with the marls and chalks and fine impervious clays come in above. The structure of the area is also favourable for accumulation. We have the strata rising for many miles from N. to S., and then a rather abrupt flattening which takes place in the Keri Marsh area. Thus we have an extensive field from which drainage and migration has been possible under various compelling forces and a distinct structure in which the moving oil would be trapped. Unfortunately the simplicity of this structure has been disturbed by later thrust movements which have caused the oil to move again, and to accumulate in subsidiary folds, and also some very evident loss by escape at the surface.

In dealing with the oil occurrences in Madagascar* the author showed that in that Island the conditions were such as to suggest that the volcanic dykes and plugs present may have played some part in the formation of oil in the associated sedimentary rocks. In the case of Zante there seems to be a possibility that organic matter present in these Miocene strata may have been converted into oil by pressure when the beds were being overthrust and contorted. Such laboratory researches as have been carried out with the object of ascertaining whether such changes can be caused by pressure seem to lead to adverse conclusions †— but is it possible to obtain in the laboratory conditions which can be paralleled with those present in a field of this description ? One is inclined to doubt that human ingenuity can reproduce the effects of a long period of compression and crumpling. The author has reached no definite conclusion on this matter, he puts forward the suggestion for consideration and discussion.

Again, we cannot, in the present stage of investigation in this field, entirely discard the possibility that the oil may have had a more deep-seated source of origin which was clearly in Sir Boverton Redwood's mind. It may possibly have originated in the underlying Cretaceous-Eocene limestones and may have migrated upwards by way of the deep-seated faults which are undoubtedly present in the area. We have seen that black, bituminous limestone beds occur in this series on Mount Skopos. Oil is found in connection with Cretaceous limestones on the mainland of Greece, and bituminous limestones belonging to both Cretaceous and Eocene are known both on the mainland and in neighbouring islands of the Ionian Archipelago[26, p. 135 & 29, p. 21]. Some years ago the author investigated an area in Thrace, in which liquid petroleum was present in association with Nummulitic limestones, though not in circumstances which would warrant commercial exploitation. It is, however, established that the limestones of both the Cretaceous and Eocene are bituminous and may be oil-bearing in the Græcian area and so may be regarded as a possible source of origin. Interesting possibilities arise from such considerations, especially in the case with which we are dealing. There is, however, no need to go further into this for it seems better to accept the more simple conclusion that the oil which has been obtained originated in the Miocene series in which it occurs. This conclusion does not, however, preclude the possibility of deeper and totally independent oil bearing strata being present in the underlying Cretaceous-Eocene group.

---

* *J.I.P.T.*, Vol. XV, No. 72, pp. 2-32.

† Graham and Skinner. "Note on the Composition of oil found in Proximity to certain Coalseams of North Staffordshire in relation to its mode of Formation. *Trans. I.M.E.*, Vol. LXXIII., Part 3, pp. 349-355.

VI. Conclusion.

The author is conscious of deficiencies and omissions in this paper. In the circumstances some of these are unavoidable. He has endeavoured to give a fairly complete geological description of an island, which has for many centuries been of interest from an "oil man's" point of view, and his excuse is that no serious attempt has hitherto been made to give an account of the tectonics and geological structure of the Island.

VII. Bibliography (in part after Issel).

[1] "Herodotus," Vol. IV., 195. B.C. 484-425.

[2] Pliny. "Natural History," Vol. XXXV., Chap. 51, A.D. 70.

[3] Castellan. "Lettres sur la Moree et les Iles de Cerigo, Hydra et Zante." Paris, 1808.

[4] Mercati. "Saggio storico e statistico della citta e isola di Zante." 1811. Manuscript in the Foscolian Library in Zante.

[5] Holland. "Travels in the Ionian Islands, Albania, Thrace and Macedonia." London, 1812-13 and 1815-19.

[6] Virlet d'Aoust. "Notes sur les Sources et Mines d'Asphalte ou Bitume Material de la Grece et des quelques autres Contrées." *Bull. de la Soc. Geol. de France*, Vol. IV., P. 203. 1833-34.

[7] Messala, C. "Narrazione del terremoto di Zante." Malta, Izzo, 1841.

[8] Davy. "Notes and Observations on the Ionian Islands." London: Smith, 1842.

[9] Strickland. "On the Geology of the Island of Zante." *Proc. Geol. Soc., Lond*, Vol. II., P. 572. 1838.

[10] Strickland. "On the Geology of the Island of Zante." *Trans. Geol. Soc.*, Ser. II. Vol. V. Pt. 2, P. 403. 1840.

[11] Unger. "Wissenschaftliche Ergebnisse eine Reise in Griechenland und die Ionischen Inseln." Wien, 1862.

[12] Barbiani, D. G. e Barbiani, B.A. "Memoire sur les tremblements de la terre dans l'ile de Zante." Mem. del'Acad. de Dijon, Vol. XI., P. 1. 1843.

[13] Coquand, "Description Geologique des Gisements Bituminifere et petroliferes de Selenitza en Albanie et de Chieri dans l'ile de Zante." *Bull. de la Soc. Geol. de France.* Vol. XXV., P. 20, 1868.

[14] Fuchs, T. "Die Pliocenbildungen con Zante und Corfu." *Sitzungsben der K. Akad. der Wissensch, Mathem. Naturwiss. Classe.* Vol. LXXV., Band IV., P. 309. 1877.

[15] Cordella. "La Grece sous la Rapport Geologique et Mineralogique." Paris, 1878.

[16] Riemann, O. "Recherches Archeologiques sur les Iles Ioniennes." *Biblio. de l'Ecole française d'Athene et de Rome.* Paris, 1880.

[17] Philippson, A. "Ueber die Altersfolge der Sedimentformationen in Griechenland. *Zeitschr. der Deutsch Geol. Gesellsch.* S. 150. 1890.

[18] Philippson, A. "Bericht ueber eine Reise durch Nord und Mittelgreichenland." *Zeitschr. der Gesellsch. fur Erdkunde zur Berlin.* Vol. XXV., Band. 1890.

[19] Philippson, A. "Der Peloponnes." Berlin, 1892.

[20] Partsch, J. "Die Inseln Zante." *Dr. Petermanns Mitteilungen*. 37 Band. 1891.

[21] Forster, W. G. "The Recent Earthquakes in Zante." *The Mediterranean Naturalist*, Vol. II., P. 23. Malta, 1893.

[22] De Rossi, M. S. "L.Odierna attivita sismica dell'Archipelago Greco studiata in Italia." *Atti dell' Acad. post. del Nuovi Lincei, Tomo.* Vol. XLVI. Roma, 1893.

[23] Issel, A. "Cenno sulla costituzione geologica e sui fenomeni geodinamici dell'isola di Zante. *Bolletino del r. comitato geologico d'Italia.* Serie III. Vol. IV., Pp. 144-182. 1893.

[24] Cooke, J. H. "Contribution to the Stratigraphy and Palæontology of the Globigerina Limestones of the Maltese Islands." *Q.J.G.S.* Vol.LII., Pp. 461-462. 1896.

[25] Mitzopoulos, Prof. K. "Die Eruption der Pechquellen von Keri in Zante und ihre Vulkanische Natur." *Abdruck aus Dr. A. Petermann's Geogr. Mitteilungen. Heft.* Vol. VII. 1896.

[26] Redwood, Sir Boverton. "A Treatise on Petroleum." Third Ed., Vol. I., Pp. 28 and 135. 1913.

[27] Howell, George. "Is there Oil in Greece." *Oil Engineering and Finance.* Pp. 139-143. March 1, 1924.

[28] Cook, A. B., and Despard, C. "Historical Records Relating to Oil." *J.I.P.T.*, Vol. XIII., No. 60, Pp. 124-134. 1927.

[29] Wray, D. A. "Greece: Its Geology and Mineral Resources." *Min. Mag.* January and March, 1929.

[30] Höfer, H. "Das Erdölvorkommen auf der Insel Zante (Zakinthos)." Öster Z. f. Berg. und Huttenw. 53. No. 265. 1905.

[31] Lederer, J. J. "Bergöl in Zante." Berg-Hütt.-Zeit., bd. XXXIII., P. 429. 1874.

DISCUSSION.

The President, in thanking the author on behalf of the Institution, said Dr. Wade had given an extremely interesting, instructive and well-explained lecture on the geology of the island of Zante. He had been particularly struck by the way in which the author had been able to correlate maps and pictures of scenery. He had not realised that Zante was a producing country.

Judging by the rather scanty data contained in the paper, it would seem that the oil was similar in character to the asphaltic oils of Mexico. The high specific gravity of the kerosine and lubricating oil fractions, and the sulphur content, were indications as was also its possible origin from marine vegetation.

Prof. V. C. Illing said he had wished to thank the author for the presentation of new data on an area about which little was known geologically.

Any criticism that he would give on the paper could only be of a general nature, for he had no personal knowledge of the area. He thought, however, that he ought to make a mild protest to the author on one point, namely, the question of giving stratigraphical

conclusions without palæontological data to support them. He referred to it in connection with the present paper because there were one or two points of stratigraphical interest in which palæontological evidence was vital to the subject and this was not given. For instance, the Cretaceous limestones, he understood from the author, could be traced up to the Eocene. He would like further evidence on this point because transitions from Cretaceous to Eocene were unusual, and therefore ought to receive adequate treatment when they were found. In the area dealt with by the author it was surprising to him, he admitted, that such a transition should occur, for he noted that the evidence of the Miocene suggested shore line conditions, whereas this early Tertiary transition suggests rather a trough of the geosyncline.

He had not gathered what evidence the author had for placing the limestones at Skopos in the Eocene. He would like to know whether there was palæontological evidence for this, or whether it was based on lithological grounds. He asked this because the author's elucidation of the cross section hinged largely on this point. The Miocenes between the main Cretaceous-Eocene limestones and the Skopos limestone certainly showed a considerable amount of folding in those sections, but that in itself was not evidence of regional overthrust. Much of it could be flow of plastic material between rigid beds, and the speaker still felt unconvinced that the data submitted was not due to this feature rather than to broad movements of an overthrust type. Before Zante could fit into the picture as a part of the regional structure of the Ægean this point woud have to be cleared up.

Coming to the question of the oil, the speaker understood the author postulated a terrace of Miocene or pre-Miocene age as the original cause of the oil concentration. He wished to know on what evidence the author had unravelled the post-Miocene folding and got to a pre-Miocene terrace. That would require certain specific evidence, and he was not clear as to how the author had arrived at his conclusion.

With regard to the origin of the oil, it seemed to him that it would not do to stress unduly the possibility of pressure as a source of oil and agree with the author that pressure was an unlikely agent to do the work.

With regard to the possibility of oil in bulk, the author had not stated what thickness of Miocene cover existed in the actual oilfield. He would like to get an idea of the thickness of the cover, because that was associated with the oil possibilities. It seemed to him that the condition of denudation on this refolded monocline did not leave much hope of large oil pools. He admitted that oil

had been found in very curious and very involved structures on occasions, but hardly oil in quantity with the exposure of the underlying basement rocks so near the oil pool.

Mr. T. Dewhurst said that, like Prof. Illing, he found it difficult to understand fully the geology of Zante, but he thought the difficulties were due to two causes. In the first place, the area was isolated and it was difficult to fit the geology into a mental picture of the general geology of the region ; Zante was an isolated block, as it were, of a geological picture puzzle. In the second place, even the oldest rocks exposed on the island were only of Upper Cretaceous (Turonian) age, and it followed that the region must have undergone a long, and possibly a chequered, geological history before even the oldest rocks now exposed on the island were deposited. He desired to ask the Author whether there were any indications on the mainland of an old North-west–South-east earth movement as he suspected that the complicated structure near Mount Skopos was due to a recrudescence of such a movement in late Tertiary times.

The principal earth movement which had affected the island was a South-west–North-east movement, and there had been several phases of that movement, the most notable of which were post-Eocene, post-Miocene and post-Pliocene in age. In addition, there might have been minor intermediate and even later phases of this earth movement. However, although the oldest of the observed phases of the movement was post-Eocene in age he suspected that earth movement in a South-west–North-east direction was initiated in pre-Turonian times. The two earth movements he had mentioned had probably been in operation in pre-Turonian times and had impressed on the region the general conditions favourable to the formation of oil during the deposition of the rocks now exposed on the island. At the dawn of Turonian times the geological stage was set for the enactment of the succeeding events. He was inclined to agree that, during the deposition of the Cretaceous and Eocene rocks, the conditions might, at certain stages, have been favourable for the formation of oil and he believed that the little oil which occurred in those strata was probably indigenous to the containing beds. However, he doubted if much oil was formed in the Zante region in Cretaceous and Eocene times.

As regards the oil forming conditions, he regarded the Oligocene earth movement as having been very important, as he believed that the conditions, which in Cretaceous and Eocene times were favourable for the formation of a little oil, became much more favourable owing to changes produced by the Oligocene earth movement. The gypsum in the Upper Miocene showed that at

that time inland sea conditions obtained, and, as there was probably little earth movement in Miocene times, he suspected that the inland sea conditions were either initiated or greatly intensified by the Oligocene movement and that there was partial separation from the main sea after the Miocene trespass took place. He was of opinion that the conditions for the formation of oil were most favourable immediately after the Miocene trespass, and therefore he was in complete agreement with the Author's principal conclusion that the main oil of Zante was indigenous to the containing strata, that is to the basal beds of the Miocene.

In regard to the hypothesis that the formation of the oil was effected by pressure due to earth movement, he thought there was very little difference of opinion between the Author and himself. He suspected that the Author, in order to stimulate discussion of the difficult and important subject of the origin and formation of petroleum, had in this case erected an Aunt Sally and then could not resist having a few shies at it himself. Indeed very little remained of the hypothesis after the Author had finished with it. As stated in the paper, the hypothesis was not supported by the results of laboratory researches. Moreover, it was evident that most of the post-Miocene earth movement took place not only after the formation of the oil, but subsequent even to its migration and accummulation.

He thought he might digress, in company with the Author, and state that he did not believe that igneous activity in Madagascar had influenced the formation of oil in that country.

In conclusion, he expressed the hope that the Author would produce another paper on the subject when he had completed the examination of his extensive palæontological collections.

Mr. A. Beeby Thompson said that it was only by detailed descriptions of those more or less sporadic occurrences of oil which formed small fields that it would be possible to advance our ideas concerning the origin of oil. He knew Greece fairly well, and had had occasion to cover long distances devoid of any manifestations of oil, yet now and again one would find distinct indications of oil and gas, or occasionally bituminous limestones. His interest in Zante had been specially stimulated by the fact that he transferred a drilling plant from Zante to Portugal twenty-five years ago, when one of the major oil interests had abandoned operations after a certain amount of unsuccessful drilling had been undertaken.

A very interesting point brought out in the paper was that those sporadic occurrences of oil always occurred amidst very disturbed ground. Although Prof. Illing and Mr. Dewhurst had particularly stressed the point that pressure had nothing to do with the origin of oil he could not help feeling that tectonic movements

were not unconnected with these sporadic accumulations. He could refer to several cases similar to Zante. In Somaliland, for instance, only one small area in the Colony where very disturbed conditions existed gave signs of oil, and yet in that particular case the conditions warranted the belief that a small oilfield could be successfully developed. In Zante only the small region where the rocks were greatly disturbed seemed to give hopeful prospects, and along the whole strip where the Nummulitics outcropped, there was apparently no further noteworthy occurrence of petroleum. It seemed to him, therefore, that one had to attribute its presence to some very local circumstance, or possibly a combination of critical events, which caused the collection and possibly the origin of oil in that very restricted region.

He was sure that it would be with a great sense of relief to many present to deduce from the contents of the paper that Zante was unlikely to loose another flood of oil on the world. To him it appeared perfectly astounding that a production of 40 tons a day should be obtained from a well at the depth mentioned. He could only assume that the production was not sustained, but nevertheless it was very remarkable how large were the quantities of oil these small fields gave in a short period. He felt strongly that if the Institution could induce more members to come forward and give as good a description of small fields as the Author had given, they would go a long way towards elucidating some of the little-understood problems related to the origin of oil.

Mr. W. H. Cadman said, that a few years ago in the Research Laboratories of the Anglo-Persian Oil Company at Masjid-i-Sulaiman, the late Prof. Hugo de Böckh had suggested to him the possibility of some correlation existing between the high sulphur content in oils and the presence of gypsum, with which it is so frequently associated in an oil field.

After doing a certain amount of experimental work in that connection in Persia, he (the speaker) had written a paper* which claimed to confirm Prof. de Böckh's theory, but which was rather severely criticised at the time by Dr. Murray Stuart.

Dr. Wade, in his paper, has traced the Gypsum Series in the Island of Zante, and its outcrops, and has given an analysis of a sample of the oil by Hackford, which shows it to contain more than 6 per cent. of sulphur. Thus Dr. Wade's work gives further evidence of the possibility of there being a definite correlation of some kind between the presence of sulphur in petroleum and the occurrence of gypsum.

* "The Origin of Hydrogen Sulphide in Persian Natural Gas and a Method of Preparing Unsaturated Hydrocarbons." *J.I.P.T.*, 1925, **11**, 487-489.

He asked the Author if the oil produced in the wells described was under pressure, whether it flowed freely or had to be pumped, and whether the gas referred to was conspicuous for high hydrogen sulphide content.

Mr. T. H. R. Garrett said that it was interesting to note that the characteristics of the Zante Miocene oil were very similar to those of the Miocene oil in Rumania—the nearest producing field to Zante—but that he thought he was right in saying that in Rumania there was only one field producing commercially from the Miocene, and that the oil was a very light filtered oil.

Although the author had said that he had not worked out the palæontology of these beds, he would like him to say exactly what he took as the limit between the Miocene and Pliocene, as there were very great differences of opinion in this matter.

Mr. J. E. Hackford said the oil found in Zante was remarkable on account of its very high specific gravity in relation to its viscosity. The sulphur content was well over 6 per cent. There was a relationship between the sulphur content of a crude oil and the content of calcium sulphate in or approximate to the oil-bearing strata.

The oil of Zante was one of the oldest oils of history; from a chemical point of view it was one of the youngest oils, the sulphur compounds being in a very unstable state.

The asphaltenes contained comparatively large quantities of oxygen, and were nearly wholly soluble in petroleum ether, but were insoluble in ethyl ether.

Mr. W. G. Weeks said that the author had referred to a thick series of blue clays which had been considerably contorted. He would be very glad if the author could tell him if he had found any evidence of the actual flow of those clays as distinguished from movement due to folding. The geological conditions of Zante appeared to be very similar in many respects to those of Trinidad, where also there were large masses of dark clays which had been violently contorted. In some of the wells there he had found it almost impossible to establish any satisfactory correlation unless one assumed that the black clays had actually been able to flow under pressure, i.e., with a superincumbent mass holding them in, but the pressure moving them about just as pressure on a tube of tooth-paste would move the paste from one part of the tube to another. If the author could throw any light on that problem he would be very much interested.

Dr. Wade (in reply) said that he agreed to some extent with Prof. Illing's criticism on the necessity for palæontological work. Prof. Illing would find that his criticism had been anticipated and

to some extent, met in the paper itself. He felt, however, that there was sometimes a tendency, distinctly modern, to make a fetish and bugbear of Palæontology. Without wishing to make out a case for careless and slipshod geological work, he agreed with Mr. Beeby Thompson that papers of this kind based on careful and, perhaps he might add, competent field work were often worth while. He had had occasion lately to read through many of the papers published by the Geological Society in its early days. Quite a number of these were geological descriptions based on a minimum of palæontological detail. The authors of these papers made mistakes, perhaps, but the percentage of error was, as a rule, trifling, while the subsequent corrections made as the result of later palæontological work have had little or no effect upon the structural determinations or the general order of stratigraphical succession. In consequence many of these papers are of the utmost value to the field man. He thought it was both necessary and opportune to say this because he was aware of papers which could have, and certainly should have, been written, but the authors were afraid of the palæontological work for which they could find neither the time nor facilities. One such paper, and a very valuable one, had, to his knowledge, been on the stocks for nearly twenty years. Palæontology was becoming more and more the work for specialists with ready access to both museums and libraries. The geologist who spent most of his career in the field was handicapped in these directions, but what a lot of useful geological knowledge and information sometimes died with him. While fully aware of the importance and necessity for palæontological work, he thought that the subject was sometimes used in these days to throw a cloak of Aesculapian mystery round the rustic figure of Geology.

However, the recognition of both Cretaceous and Eocene formations as dealt with in the paper was based on palæontological data. Strickland recognised the presence of both formations on these grounds as far back as 1838, and also suggested that the overlying formations belonged to Miocene and Pliocene.

With regard to the junction between the Cretaceous and the Eocene, the paper showed that there was a difficulty which could only be cleared up by further work of a palæontological nature. There may be a definite break between the two. The occurrence of Nummulites in the Windmill Hill at Keri and the difficulty of finding and tracing the Nummulitic beds along the margin of the limestone range were regarded by the author with suspicion.

Regarding the limestones of Skopos, the age had been determined as the paper showed by lithological comparison with beds of known Cretaceous age, both on the mainland and in other parts of the Island. The limestones possessed distinctive characteristics which

differentiated them from anything which had been observed in the younger formations, but facilitated identification by comparison. The author was in agreement with other geologists, such as Issel, in regarding these rocks as belonging to the Cretaceous-Eocene group. Palæontological work remains to be done.

With regard to the folding in the soft beds of the Miocene, the conclusions arrived at by Prof. Illing were in agreement with those set forth in the paper. The overfolding in Skopos is, however, another matter. Most earlier writers referred to the complicated structure of this mountain mass, and had left it at that. He had endeavoured to unravel it, and could see no alternative to the interpretation of the geological section across the outcrops which had been shown.

The lantern slides had shown that "terrace" structure existed in the Miocene beds exposed near the oilfield area to-day. He also thought that such terracing began to come into being in Miocene times, though he had not so stated in the paper. The geological evidence indicated that some uplift took place in pre-Miocene times, and that the older limestones were present as reefs in the early Miocene sea. At the same time, depression was taking place where the thick series of deposits covering the median plain of the Island were laid down, and it is obvious that depression in this area was taking place at a more rapid rate than elevation of the older limestone mass. If this be so and such a state of things continued, as it evidently did, the beds of the Lower Miocene would certainly take on a terraced structure between the older limestone outcrop and the median plain of Zante. Anyhow, if it be accepted that the oil had migrated towards the limestone mass before the onset of the movements which distorted the soft Miocene strata, it is difficult to see how it could have been retained without the presence of some such structure.

The actual thickness of the Miocene cover in the oilfield area itself is not more than 500 to 600 ft. With regard to the quantity of oil which could be present at such shallow depths, he referred to the Belle Vue field in Northern Louisiana, where, at the time of his visit a few years ago, wells between 200 and 300 ft. in depth were producing up to 6000 barrels of oil a day.

Mr. Dewhurst asked whether there were any indications on the mainland of an old North-west–South-east earth movement. There were such indications in the folded zone of Central Greece. He agreed with Mr. Dewhurst that recrudescence of old movements was to be suspected in Zante.

He was in general agreement with Mr. Beeby Thompson's remarks, and knew of many cases which would support his idea that tectonic

movements were not unconnected with sporadic accumulations of oil. He thought that there was room for further inquiry in this direction.

Mr. Cadman had raised the question of the connection between gypsum deposits and high sulphur content in oils. He thought he could leave that for Mr. Hackford to deal with. The oil in the Zante wells was under considerable, though not great, pressure, and flowed freely when wells were brought in. Later they had to be pumped. There is no very evident smell of hydrogen sulphide in connection with the gas present.

In reply to Mr. Garrett, he could only say that the definite break at the top of the Miocene succession of Zante was taken as the end of deposition in this period. The strata associated with conglomerates and breccias above, and which lie unconformably on the Miocene formations, were regarded as Pliocene. Such palæontological work as had been done confirmed this, but until further work had been accomplished on the fossils no correlation with the accepted divisions of Miocene and Pliocene could be suggested with any degree of accuracy.

That flow movements as distinct from folding have taken place in the clay formations exposed on the Island is readily seen in some of the cliff sections along the coast, but he thought that flow on the scale envisaged by Mr. Weeks was more characteristic of the clay formations seen by him in Papua.

On the motion of the President, a vote of thanks to the author was carried with acclamation, and the meeting terminated.

The Crystallisation of Paraffin Wax. Part II.*

By E. Katz.

In the first part of this work[1] the crystallisation of paraffin wax[2] was dealt with and the various forms of crystals observed, and the conditions under which they were formed, were characterised.

In the present paper it is intended to show, by means of experiments and observations, the relationship between the plate and needle forms of paraffin crystals, and to describe the conditions under which they develop and can exist permanently.

Previous workers[3] on the subject of paraffin wax crystallisation explain in various ways the relationship of both crystal forms and put forward differing conjectures and hypotheses with the aim of solving the problems of the cause of transition from one crystal

---

* Paper received September 4, 1931.

[1] *J. Inst. Petr. Techn.*, 1930, **16**, 870-888, in which the author wishes to make the following corrections: Page 874, para. 4, should read:—

"4. *Crystallisation in Needle Form.*—If the crystal substance from dissolved paraffin wax is obtained from the same solution as that from which the plates were obtained, but saturated at a temperature of ca. 45°–50° C., crystals like needles, and thus so called, are observed. In this case some plates are also seen."

Page 883, lines 32-34. For "Photos 34 and 35, Plate IX.," read "Photo 41, Plate XI.," and for "Photo 27, Plate VII.," read "Photo 35, Plate IX." Line 40: for "cut off" read "taken off."

[2] In their work on "Properties and Structure of Paraffin Waxes and Ceresines," Sachanan, Zherdeva and Vasilyev (*Nat. Petr. News*, 1931, **23**, (16), 49-52; (17), 68-70; (18), 51-53; (19), 71-74) define the products obtained by normal manufacture., *i.e.*, by common filtration and sweating, as paraffin. The product obtained by special methods of dewaxing, *e.g.*, centrifuging, filtration with filter aids, settling, etc., is defined as ceresine. The material used in the present work is regarded as paraffin, in the sense so defined.

The crystallisation of ceresine, as thus defined, was observed in the present work to proceed in a different manner to that of paraffin wax as described in Parts I. and II. of this paper. Apart from differences not dealt with here, the chief difference is the absence of the needle form of crystal which is characteristic of paraffin wax (see later).

[3] Carpenter. "The Physical and Chemical Properties of Paraffin Wax." *J. Inst. Petr. Techn.*, 1926, **12**, 288-315.

Padget, Hefley and Henriksen. "Wax Crystallisation." *Ind. Eng. Chem.*, 1926, **18**, 832-835.

Buchler and Graves. "The Petroleum Waxes." *Ind. Eng. Chem.*, 1927, **19**, 718-724.

Rhodes, Mason and Sutton. "Crystallisation of Paraffin Wax." *Ind. Eng. Chem.*, 1927, **19**, 935-938.

Tanaka, Kobayashi and Ohno. "Studies on Crystallisation of Paraffin." *J. Fac. Eng.*, Tokyo, 1928, **17**, 275; *J. Inst. Petr. Techn.*, 1929, **15**, Abstr. No. 152.

Burrell. "Composition and Properties of Wax." *Oil and Gas J.*, 1928, **27** (22), 130.

Padget. "The Crystallisation of Petroleum Wax." *Petr. Eng.*, 1931, **2**, No. 4, 80-84.

form to another, the conditions under which this change occurs, and the conditions necessary for the permanent existence of any particular crystal form.

Ferris, Cowles and Henderson[4] made observations different from those of other workers. They note that paraffin consists of single (individual) groups of components differing from each other in crystalline form. The plate component retains its crystal form through the varying conditions during its crystallisation, and the needle component acts in a similar way. The authors reject the theory that the viscosity of the solvent forming the mother liquor, the conditions of cooling, or the concentration of the paraffin in the solution, influence the form of crystal arising from the crystallisation, and they regard the crystal form as being to a great extent determined by a certain component of the paraffin.

While studying the differences between the crystallisation of paraffin wax and of ceresine, a similar factor influencing the crystallisation was observed and is attributed to differences of chemical composition. Ceresine does not show a needle form of crystal, but crystallises in plates or similar forms only, *independent of conditions*. It can be said, in agreement with the observations of Ferris, Cowles and Henderson, that ceresine belongs to the group of paraffin products which crystallises in a given form independent of conditions.

During the present work the existence of particular groups of components possessing always a crystal form characteristic of them was not observed. It was seen that the course of the wax crystallisation process, *i.e.*, the development of any particular crystal form, depended only on the concentration of paraffin in the solution and the temperature at which crystallisation began.

The observations of Sachanen, Zherdeva and Vasilyev[5] that paraffin does not crystallise in plates or needles, but in strips, and that ceresine crystallises in the needle form, do not agree with the observations made during this work. It should be mentioned here the present author (like others) describes as a needle that crystal form which develops according to the scheme described in Part I. (Figs. 4 to 13), and also the long worm-shaped crystals of the soft paraffin wax (Part I., Photos 45 to 48, Plate XII.). Although the delicate filaments and pieces can easily be mistaken for needles (see Photos 1 (*a*), 2 (*a*), and 3, Plate I.), the revolving table of the petrographic microscope shows their real form to be different shapes of foliated or laminated masses (Photos 1 (*b*) and 2 (*b*), Plate I.), very often mutually intergrowing as in Photo 2. From

[4] "Composition and Crystal Forms of the Petroleum Waxes." *Ind. Eng. Chem.*, 1931, **23**, 681-688.

[5] *loc. cit.*

the point of view of their development and structure, they are plates. When a plate, by some cause affecting its deposition, grows faster in one direction than in the other, it gives a shape like a needle or strip, but nevertheless remains a plate and behaves as a plate during manufacture (filtration and sweating).

It was noticed that the crystals (*e.g.*, from paraffin of 50° C. melting-point) developed from dilute solutions, *i.e.*, forming and growing at lower temperatures (about 20° C.) have the foliated or laminated form of plates, and this form remained throughout the whole crystallisation process until the formation was complete. On the other hand, it was observed that the crystals from concentrated solutions, *i.e.*, solutions from which crystallisation starts at higher temperatures (for this grade of paraffin, at about 47° C.), are at first in the form of a plate, but this form soon changes into, and remains throughout the process as, that of a needle. The product resulting from crystallisation of such solutions always appears as a mass of needle crystals.

In order to explain these phenomena, the crystallisation of paraffin from solutions of gradually increasing concentration was systematically examined. The paraffin fractions used were those mentioned in Part I., Tables 1 to 5, and reference will be made to these.

It was observed that as the concentration of the solution is increased, a point is reached, at a definite saturation temperature,[6] at which plates cease to exist and the needle form of crystal begins to appear. This form is obtained continuously with increasing concentrations up to 100 per cent. of paraffin, and also during the cooling of melted pure paraffin. The finished solid paraffin, therefore, always has a needle structure (see also Part I., para. 7, page 877).

[6] The saturation temperature was taken as the temperature at which, on cooling the solution, a cloud caused by paraffin crystals separating was first observed near the bulb of the thermometer with which the solution was stirred in a small vessel. If a dark oil is used as the solvent, the observation of this point is difficult (Sullivan, McGill and French: "Solubility of Paraffin Wax in Oil." *Ind. Eng. Chem.*, 1927, **19**, 1042-1045). Cooling even in small vessels is not uniform, and vigorous stirring when the temperature is near the saturation or solidifying point, causes air bubbles, which make the observation difficult.

The following method was therefore used in this work; a small-bulb thermometer was immersed in the warm solution and removed with a small drop of the solution on it. The thermometer was then revolved swiftly and a thin film of the solution made on the bulb. During continued revolving, the reflection of light from the bulb was observed and, when the reflection began to cloud, the temperature was taken as the saturation temperature. This determination was repeated several times.

The saturation temperature is about 2° to 4° C. above the solidifying point of the solution, depending on the concentration (Sachanen, "Ueber die Löslichkeit des Paraffins und die Erstarrung der Paraffinhaltigen Produkte." *Petroleum*, 1925, **21**, 735-740).

In order to crystallise paraffin in the form of needles from a solution, a certain concentration is necessary in relation to the saturation temperature corresponding with this concentration. The concentration at which plates cease to exist and needles begin to form is called the *concentration of change*, and the saturation temperature at this concentration the *temperature of change*. In other words, the temperature of change is the saturation temperature of a paraffin solution, which must be obtained (*e.g.*, by increasing the concentration) if it is desired to pass from the plate sphere to the needle sphere to obtain needle crystals.

The values of concentration and temperature of change can be determined with great accuracy, as the characteristic percentage of paraffin in a solvent is related to the characteristic temperature at which the paraffin begins to separate.

The change from one form to the other is clearly observed, the limits of difference being about 0·5 to 1·0 per cent. concentration, with the corresponding difference in saturation temperature.

If a paraffin fraction of 51·6° C. melting-point (Part I., Table 2, Fraction 4) is dissolved in kerosine, the concentration being increased gradually, and the crystals formed on cooling (after each time the paraffin has been completely dissolved by heating), are examined, it will be seen that the needle form of crystal first appears when the paraffin content is 67 to 68 per cent. of the solution. All the crystals obtained from concentrations below this figure are of the plate form.[7] The concentration of 67 per cent. of paraffin (the fraction above) in kerosine corresponds with a saturation temperature of 46° C., and 68 per cent. with 46·4° C. The concentration of change for paraffin of 51·6° C. melting-point and kerosine is, therefore, between 67 and 68 per cent., and the temperature of change for this paraffin is between 46° and 46·4° C.

Photo 4, Plate II., shows crystals of paraffin wax of 56·4° C. melting-point (Part I., Table 3, Fraction 3) obtained from a solution of 66 per cent. in kerosine, while Photo 5 shows crystals of the same paraffin from a 70 per cent. solution. Photo 6, Plate II., shows crystals from an Asiatic wax of 54° C. melting-point (Part I.,

[7] It must be noted here, as already mentioned, that the plate crystals can easily be mistaken for needles. Seen in the mother liquor, the floating crystals appear as thin filaments resembling thin needles (Photos 1(*a*), 2(*a*) and 3, Plate I.), but when examined under the microscope in polarised light their true structure is seen (Photos 1(*b*) and 2(*b*), Plate I.).

If the plate crystals are very thin and are laying parallel to the surface of the table, they are often, when observed in polarised light, isotropic (Rhodes, Mason and Sutton, *loc. cit*). If the revolving table does not show their true structure, the preparation under observation must be thickened (*e.g.*, observed in drops) so that the crystals lie in different planes and can be recognised as plates. It is possible to identify the true form of the crystal by macro-observation with practice.

PLATE I.

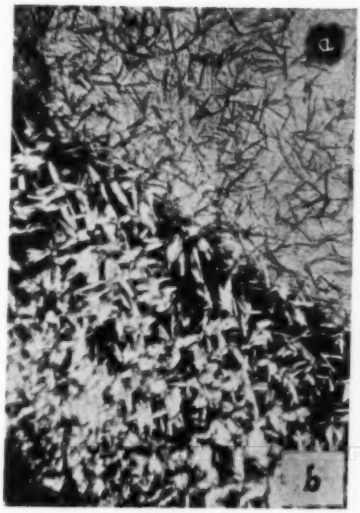


FIG. 1.

Ceresine, m.-pt. 72° C., obtained from heavy supervacuum oil-wax distillate by special dewaxing method, crystallised from petroleum. (Boryslaw crude—distillation at about 2 mm. Hg. abs.) (*a*) ord. light; (*b*) pol. light. Magnification about 280.

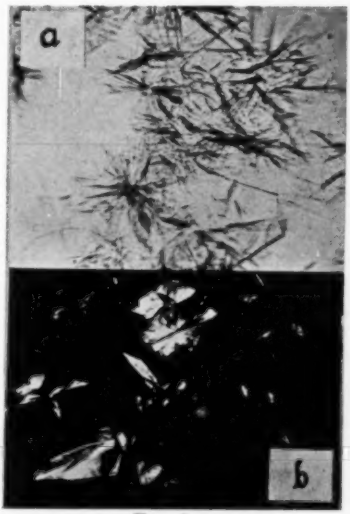


FIG. 2.

Ceresine as Photo 1. Crystallised from carbon disulphide. (*a*) ord. light: (*b*) pol. light. Magnification about 350.

FIG. 3.

Ceresine as above, crystallised from alcohol. Ord. light, magnification about 280.

Plate II.

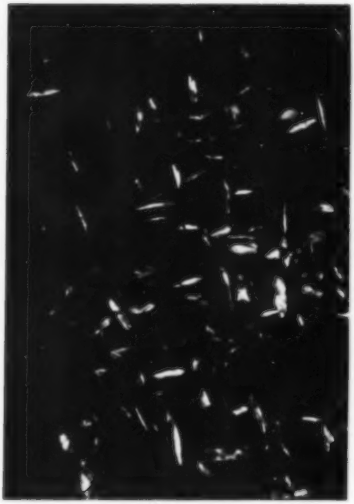


Fig. 4.

Paraffin wax, m.-pt. 56.4° C., crystallised from kerosine. Content of paraffin, 66 per cent. Pol. light, magnification about 280.

Fig. 5.

Paraffin wax, as Fig. 4, crystallised from kerosine. Content of paraffin, 70 per cent. Pol. light, magnification about 280.

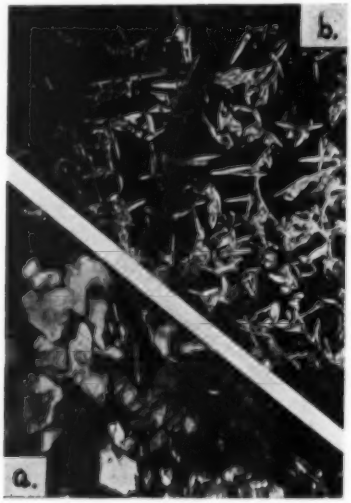


Fig. 6.

Paraffin wax, m.-pt. 54° C. (Asiatic origin), crystallised from kerosine. Pol. light, magnification about 280. (*a*) below, and (*b*) above, the concentration of change.

Table 5, Fraction 9) in kerosine, (*a*) being from below the concentration of change, and (*b*) from above this point.

These observations are illustrated in Figs. 1 and 2. Fig. 1 gives the concentration of change of different paraffin fractions in various solvents as curves. The left of each curve represents the field of crystallisation in the plate form, and the right that of the needle form. The temperature of change for each grade in the different solvents is given in °C. beside each particular point.

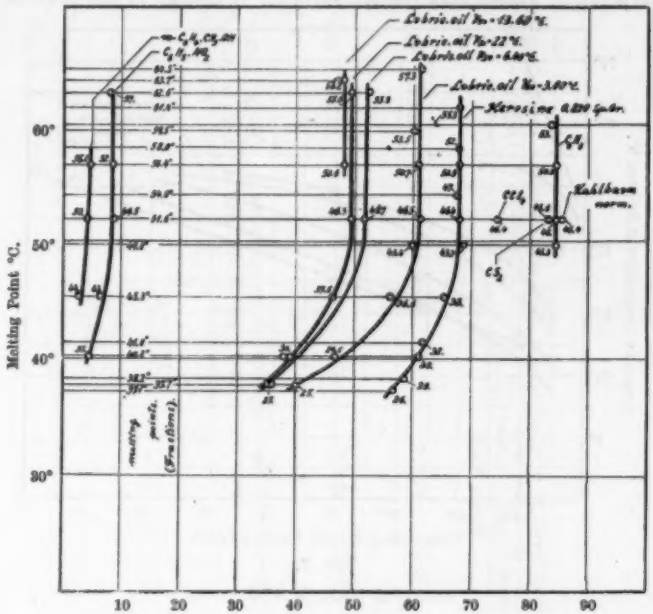


FIG. 1.

PERCENTAGE OF PARAFFIN WAX IN SOLUTION.

It will be seen that, using as the solvent a lubricating oil having a viscosity of 22° E, at 50° C., the concentration of change of a paraffin of 51·6° C. melting-point is at about 49·5 per cent., corresponding with a temperature of change of 46·3° C. With kerosine as the solvent, the concentration of change is 67·5 per cent. (temperature of change 46·4° C.), and with benzole 84 per cent. (temperature of change 46° C.). All these temperature values are within the range of 46° to 46·4° C., which is the temperature of

change of solutions of 51·6° C. melting-point, paraffin wax in lubricating oil having a viscosity of 22° E. at 50° C. (49·5 per cent.), in lubricating oil having a viscosity of 6·4° E. at 50° C. (52 per cent.), in kerosine having a sp. gr. of 0·820 (67·5 per cent.), in technical benzole (84·5 per cent.), and in normal Kahlbaum benzine (85·5 per cent.).

Therefore, in order to obtain the needle form of crystal from a paraffin, it is necessary to prepare a solution having a saturation temperature higher that the temperature of change of the paraffin.

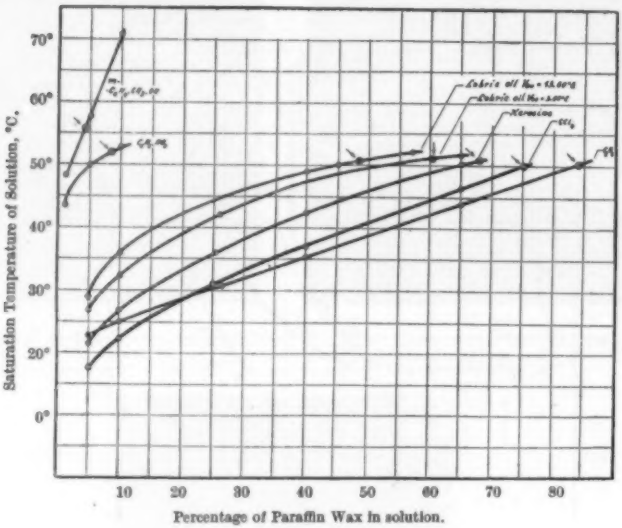


FIG. 2.

PARAFFIN WAX, 56.4° C. M.-PT.

Solutions having a saturation temperature below the temperature of change of the paraffin will yield the plate form as a permanent crystal.

Table 1 also illustrates the above, the sample referred to being the same paraffin fraction and the development of both crystal forms in different solvents being examined.

It is clear that when a certain paraffin fraction is dissolved in various solvents having different degrees of solubility of paraffin, there is a different concentration of change for each solvent at the same temperature of change. Each grade of paraffin, when

TABLE I.

Solvent.	Benzine. Normal Kahlbaum.	Benzole.	Carbon Disulphide.	Carbon Tetra-Chloride.	Kerosine.* Sp. Gr. 0.820	Lubricating Oil.‡ V/20°C. 3.6°E.	V/50°C. 6.4°E.	V/50°C. 22°E.	V/50°C. 13.6°E.	Nitro-Benzole.	m-Cresol.
Crystallises in plate form up to a paraffin content of†	85%	84%	82.5%	74%	67%	60%	51.5%	49%	47%	8%	3.5%
Crystallises in needle form from a paraffin content of†	86%	85%	83.5%	75%	68%	61%	52.5%	50%	48.5%	9%	4.5%

* From Boryslaw crude.

† Percentage of paraffin = $\frac{\text{grams solute}}{\text{grams solute} + \text{grams solvent}} \times 100$.

‡ Commercial lubricating oil from Boryslaw crude. That having a viscosity of 13·6°E. at 50°C. is obtained by a special process, and in spite of its lower viscosity is a worse solvent than that having a viscosity of 22°E. The concentration of change is therefore less.

crystallised from different solvents, has, therefore, approximately one constant temperature of change, but has different values for its concentration of change, the latter being dependent on its degree of solubility in the solvent used.

The difference between the two saturation temperatures, *i.e.*, the highest temperature at which plate crystals originate and the lowest at which needles are formed, is, as already mentioned, small and in the region of 0·2 to 0·6° C., corresponding with 0·5 to 1·0 per cent. difference in the paraffin content of the solution. The values of the temperature of change for each particular grade of paraffin are also within the limits of about 0·5° C., the corresponding concentration of change varying within the limits of about 1 per cent. The conditions under which the difference of crystal form can be most accurately observed without entering upon the initial stage of the second form are described above. In some solvents the change of form can be seen with smaller differences, *e.g.*, 7·7 per cent. of a 62·6° C. melting-point wax (Part I., Table 4, Fraction 10) in m-cresol gives plates, and 8·2 per cent. gives needles.

From Fig. 1 it will be seen that for the medium and heavy fractions of paraffin the concentration of change in any one solvent is approximately the same for each grade of paraffin, but that the temperature of change differs with each grade. Only the soft paraffins (those examined had m.-pts. of from about 46° C. to 37° C.) have a characteristic concentration of change for each grade. This is particularly noticeable when a lubricating oil of high viscosity is used as the solvent.

The characteristic value for each fraction is not, therefore, the concentration of change, but the temperature of change corresponding to it. It is only for the soft paraffins that the concentration of change is a characteristic value.

Fig. 2 illustrates also the relationship of the plate to the needle form, the curves showing the dependence of the saturation temperature of the solution on the paraffin content in a given solvent. The 56·4° C. melting-point paraffin (Part I., Table 3, Fraction 3), was selected as an example, using in succession as solvents, lubricating oil of 13·6° E. at 50° C., lubricating oil of 3·6° E. at 20° C., kerosine, carbon tetrachloride, benzole, nitro-benzole, m-cresol. The concentrations of change (marked with arrows) closely correspond for most of the solvents with one temperature of change, *i.e.*, about 50° C. (± 0·5° to 0·8° C.). With such solvents as cresol, nitro-benzole, this temperature is a little higher.

From the figures it will be seen that the temperature of change for particular fractions of paraffins is, in the case of medium and heavy fractions, about 5° to 7° C., and for soft fractions about 10° C., lower than the melting-point of the wax used.

Taking a solution of paraffin in a solvent (lubricating oil or kerosine) from which it crystallises above its temperature of change or above its concentration of change for the particular solvent, and therefore in needle form, the temperature of change of the paraffin can be ascertained by adding the solvent gradually and examining the crystals which separate. By adding 5° to 10° C. to the temperature of change (depending on whether the saturation temperature corresponding with the temperature of change shows it to be a hard or a soft paraffin (Fig. 1)) a value corresponding approximately to the melting-point of the paraffin in the solution is arrived at.

Carpenter[8] describes a similar transition temperature at which the crystal form changes at about 10° to 15° C. below the melting-point of the paraffin, and Buchler and Graves[9] also find a similar change in connection with concentration of "soft wax impurity."

As mentioned in Part I., observation of the crystals separated in the range at which needles form will sometimes also show the plate form. This can be explained as follows.

If, for example, a paraffin faction of melting-point 59·4° C. (Part I., Table 4, Fraction 3) is dissolved in kerosine, the concentration of change being 66 to 67 per cent., corresponding to a temperature of change of 52° C., crystallisation by cooling a solution containing 68 per cent. paraffin and 32 per cent. solvent should result in needle formation as far as a concentration of 66 to 67 per cent. After passing this transition point, separation of plates only would be expected. Actually the following observations were made.

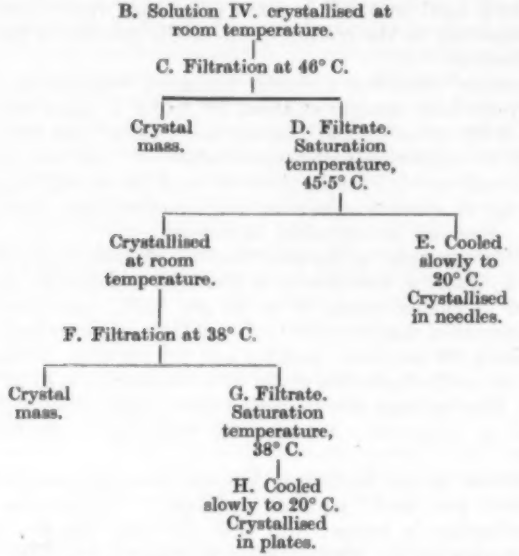
Solutions of the fraction in kerosine were prepared as follows: (i.) 60·2 per cent. paraffin, saturation temperature 49·8° C., crystallisation in plates; (ii.) 64·5 per cent. paraffin, saturation temperature 51° C., crystallisation in plates; (iii.) 66·3 per cent. paraffin, saturation temperature 51·5° C., crystallisation in plates; (iv.) 67·2 per cent. paraffin, saturation temperature 52° C., crystallisation in needles (Table II., A. I. to IV.). The last solution (iv.) was submitted to slow crystallisation at room temperature, the solution being stirred continuously (B). When the temperature of the solution reached 46° C. the crystal mass was quickly separated by filtration (C) and a filtrate (D) obtained which had a saturation temperature of 45·5° C. This filtrate was cooled slowly to room temperature (about 20° C.) and the crystals examined (E). The crystals were perfectly shaped needles similar to those given by the initial solution.

---

[8] loc. cit.
[9] loc. cit.

TABLE II.

	Solution. Paraffin Wax, m.-pt. 59·4° C. Per cent.	Kerosine. Per cent.	Saturation temperature. °C.	Crystal form.
A. I.	60·2	39·8	49·8	Plate.
II.	64·5	35·5	51·0	Plate.
III.	66·3	33·7	51·5	Plate.
IV.	67·2	32·8	52·0	Needle.


B. Solution IV. crystallised at room temperature.
C. Filtration at 46° C.
Crystal mass.
D. Filtrate. Saturation temperature, 45·5° C.
Crystallised at room temperature.
E. Cooled slowly to 20° C. Crystallised in needles.
F. Filtration at 38° C.
Crystal mass.
G. Filtrate. Saturation temperature, 38° C.
H. Cooled slowly to 20° C. Crystallised in plates.

A needle form has therefore been obtained from a solution having a saturation temperature of 45·5° C., while the primary solution of the paraffin fraction gave, at its saturation temperature of 51·5° C. plate crystals.

The needle crystal, therefore, does not cease to form during crystallisation on transgressing the value of the concentration of change corresponding with the temperature of change, but makes its appearance at lower temperatures, and even at saturation temperatures of this solution at which the initial paraffin gives plate crystals.[10] This explains the relatively small quantity of

[10] It is immaterial from which side the concentration in relation to the temperature of change is transgressed, as by increasing the paraffin content to over 67 per cent. for the case quoted needles are obtained, and by decreasing the concentration, by adding kerosine, plates are obtained.

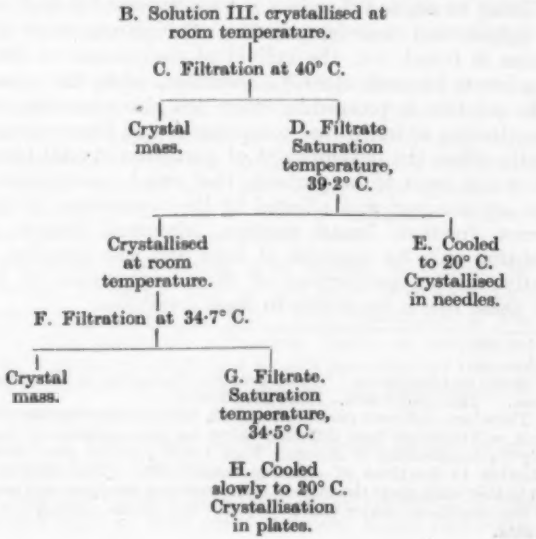
plates formed in the crystal mass separated from solutions cooled in the range of needle crystal formation. That a certain quantity of plates are formed at the end of the crystallisation process, as mentioned in Part I., and by other authors, is confirmed by the following observations.

The remainder of the filtrate (D) was cooled and filtered at 38° C. (F), the resulting filtrate (G) having a saturation temperature of 38° C. and giving plate crystals (H).

Similarly, a paraffin fraction having a melting-point of 54° C. (Part I., Table 3, Fraction 2) was crystallised, the following solutions being prepared : (i.) 64 per cent., saturation temperature 45·6° C., crystallisation in plates ; (ii.) 66·8 per cent., saturation temperature 46·6° C., crystallisation in plates and intermediate forms (transition stage) ; (iii.) 68·2 per cent., saturation temperature 47° C., crystallisation in needles. (Table III., A. I. to III.) The last solution (iii.) was cooled to 40° C. during constant stirring (B) and

TABLE III.

		Solution. Paraffin wax, m.-pt. 54° C. Per cent.	Kerosine. Per cent.	Saturation temperature. °C.	Crystal form.
A.	I.	64·0	36·0	45·6	Plate.
	II.	66·8	33·2	46·6	Plate.
	III.	68·2	31·8	47·0	Needle.


B. Solution III. crystallised at room temperature.
C. Filtration at 40° C.
Crystal mass.
D. Filtrate Saturation temperature, 39·2° C.
Crystallised at room temperature.
E. Cooled to 20° C. Crystallised in needles.
F. Filtration at 34·7° C.
Crystal mass.
G. Filtrate. Saturation temperature, 34·5° C.
H. Cooled slowly to 20° C. Crystallisation in plates.

rapidly filtered (C), the filtrate (D) having a saturation temperature of 39·2° C. and crystallising in needles (E). The remainder of this filtrate was cooled to 34·7° C. while being stirred, and filtered, the resulting filtrate (G) having a saturation temperature of 34·5° C. and crystallising in plates (H).

It is seen that by such fractional decreasing of the paraffin concentration in the solution, plate forms of crystals are obtained. It is difficult, therefore, to suppose that a substance exists, a certain concentration of which is necessary for producing needles, as has been previously suggested. The filtrate (D), obtained from the primary solution at a temperature below the temperature of change of the paraffin used, crystallised in needles, although the concentration of the wax had been decreased by the separation of the heavier fractions. (The " soft wax impurity " of Buchler and Graves[11]).

Rhodes, Mason and Sutton[12] also observed the formation of plates at the end of the crystallisation process, after the crystallisation in needle form, which was proceeding in accordance with the present observations. These authors state that the mutual relationship of plates to needles in a cooled crystal mass is dependent on the conditions of cooling.

Referring to Fig. 1, it will be seen that soft paraffin waxes require, as the melting-point falls, less and less concentration of solution for the deposition of needle crystals.

It must be realised that in a not too narrow fraction, containing the lighter and heavier paraffins, the phenomenon of mutual solution is found, *i.e.*, the individual components of the fraction are solvents for each other.[13] Therefore, while the crystallisation of the solution is proceeding, there are also occurring changes of concentration of individual components, and these changes consequently affect the development of particular crystal forms.

It would seem to be probable that exact quantitative relationships are involved and affected by the composition of the paraffin (narrow fraction, broad fraction, abnormal fration, *i.e.*, one consisting only for example of hard and soft paraffins, and also greatly varying proportions of these components of paraffin).[14] The phase rule is applicable to these conditions.

---

[11] loc. cit.

[12] loc. cit.

[13] Myers and Stegeman. " Solid Solution Formation in Mixtures of Paraffin Waxes." *Ind. Eng. Chem.*, 1928, **20**, 638-641.

[14] Therefore, different paraffin fractions, although having identical melting-points, will certainly have different values for concentration of change respectively for temperature of change. Figs. 1 and 2 do not give values generally applicable to fractions of differing constitution. The described fractions used in this work show the mutual relationship of the plate and needle crystals and the conditions under which they develop on the application of different solvents.

For their explanation, the phenemona observed require a systematic study of all the possibilities and conditions mentioned, and this work is being proceeded with.

Summing up the observations made in this present paper, it may be said that :—

The permanent existence of plate crystals is possible only in solutions in which the paraffin concentration is below the concentration of change for the particular grade of paraffin and the particular solvent respectively in solutions, the saturation temperature of which is below the temperature of change, which is about 5° to 10° C. below the melting-point of the paraffin in the solution.

The development of needle crystals is possible only in solutions in which the paraffin concentration is greater than the concentration of change for a given grade of paraffin and a given solvent respectively in solutions, the saturation temperature of which is above the temperature of change of the paraffin fraction.

To obtain needle crystals from a solution from which the paraffin crystallises in plates, it is necessary either to increase the paraffin content to the concentration of change or a little higher or, by adding a solvent which dilutes the paraffin to a lesser degree, increase the saturation temperature of this solution to above the temperature of change.

The value of the concentration of change for a given paraffin is dependent on the grade of the paraffin and on its solubility in the solvent used.

The value of the temperature of change depends only on the grade of paraffin used and is about 5° to 10° C. below its melting-point.

The plate crystals found in the range of needle crystal formation are not permanent and exist only in the first stages of crystallisation, being the initial form of a crystal which soon changes to the permanent needle form. Under certain conditions, plates and needles can both develop as permanent forms.

The development of permanent plate crystals is possible in the range of needle formation only in the more advanced stages of crystallisation, *i.e.*, towards the end. This appearance, as also the quantitative relationship of permanent plates to needles in the needle zone, is probably controlled by the properties of the paraffin fraction used (broad or narrow) and by the proportions of the individual components of the fraction.

In the range of plate crystal formation needles do not occur, the plate being the permanent form.

In the crystal development there is only one direction of paraffin wax crystallisation, *i.e.*, from plate to needle, never vice versa.

Considering these observations there are certain indications applicable to the rational manufacture of paraffin semi-refined products into finished wax. It is observed that the separation of oil from wax (oil-wax distillate) in the filter-press and by subsequent sweating gives better results when the crystals are in the needle form,[15] and it is important to know the exact conditions under which this form develops.

If, for example, an oil-wax distillate containing 18 per cent. of wax, and thus crystallising in plates, is passed through a filter-press and the slack wax sweated without previous melting, it is found that the results are not so good as if the slack wax had been melted before sweating. The slack wax from the filter-press is composed of plate crystals, but if it is melted and cooled the crystals separate in the needle form and it is in an advantageous condition for sweating.

An oil-wax distillate of about 18 per cent. wax content, as above, which crystallises in the plate form, can be made to crystallise in the needle form by the addition to the distillate of a suitable quantity of a solvent which dilutes the paraffin to a lesser degree. Thus, the saturation temperature is brought above the temperature of change of the wax in solution, and the slack wax has, without being melted, a needle structure. The solvent used may, *e.g.*, be cresol.[16]

In the first part of this work, the examination of the development and the growth of needle crystals showed that the process is probably caused by abnormal crystallisation. Similar appearances are often observed.

Lehman[17] describes bodies, the crystallisation of which does not proceed according to the general rules of crystallography. With some compounds, for instance, the crystals bend and twist during crystallisation in such a way as to give surfaces which do not occur in the normal process of crystallisation. The process described in the first part of this work is similar and, no doubt, paraffin wax crystallisation, in view of the transition from plates

---

[15] Pyhala. "Die praktische Bedeutung der verschiedenen Kristallformen des Paraffins bei der Paraffinfabrikation," *Chem. Met. Zeit. die Metallboerse*, 1929, 2134-2135, 2248-2249; "Die nadelfoermigen Paraffin-Kristalle und ihre Bedeutung fuer das schottlaendische Schwitzverfahren bei der Paraffinfabrikation," *Petroleum*, 1909, **4**, 1392; "Practical Experiments on Sweating Paraffin," *Refiner*, 1930, **9** (9), 92-98.

[16] Polish Patents applied for, 1928 and 1929.

[17] "Die neue Welt der flüssigen Kristalle," Leipzig, 1911, p. 149. A similar fact is here stated, namely, that observing the crystallisation of ammonium nitrate and other soft crystals, working with high-concentrated solutions, Lehman has noticed the growing of crystals in curved plains.

to needles, is proceeding abnormally and the needle forms are abnormal crystallographic forms.[18]

An agent that would cause this abnormality in crystallisation has not yet been found, but it may be that the cause is hemimorphism of plate crystals[19] appearing in concentrated solutions. It is also possible that the capillary constant plays a part in the crystallisation of those soft crystals.

Summary.

The conditions under which the plate and needle forms of paraffin wax crystals are developed and exist are given, and the mutual relationships of both forms of crystal are examined.

The concepts of "concentration of change" and "temperature of change" are introduced, and are regarded as being determining factors of the formation of one or other crystal form.

The development of the needle form is compared with analagous cases in the abnormal crystallisation of other bodies.

The author desires to record his thanks to Prof. Dr. S. Pilat, who has made valuable suggestions during the course of the whole research, and to the Petroleum Syndicate of Lemberg for samples of Asiatic paraffin wax for comparison with the Polish samples.

Laboratory of Petroleum Technology,
Lemberg, Poland.

Bibliography.

Lehmann, *Zeit. für Min. J.*, 1877, **110**, 482.

E. Pyhala. "Die nadelfoermigen Paraffin-Kristalle und ihre Bedeutung für das schottlaendische Schwitzverfahren bei der Paraffinfabrication." *Petroleum*, 1909, **4**, 1392.

Lehmann. "Die neue Welt der flüssigen Kristalle." 1911, p. 142.

A. N. Sachanen. "Ueber die Loeslichkeit des Paraffins und die Erstarrung der Paraffinhaltigen Produkte." *Petroleum*, 1925, **21**, 735-740.

J. A. Carpenter. "The Physical and Chemical Properties of Paraffin Wax." *J. Inst. Petr. Techn.*, 1926, **12**, 288-315.

F. W. Padgett, D. G. Hefley and A. Henriksen. "Wax Crystallisation." *Ind. Eng. Chem.*, 1926, **18**, 832-835.

C. C. Buchler and G. D. Graves. "The Petroleum Waxes." *Ind. Eng. Chem.*, 1927, **19**, 718-724.

---

[18] Lehmann, *Zeit. für Min. J.*, 1877, **110**, 482, states, under the heading "On Growth of Crystals. Anomalies of Structure. Paraffin Wax," that cooling the hot saturated solution of paraffin wax in benzole or acetone, he was able to get foliated shapes of crystals, which were of such strangely curved forms, that they had rather the appearing of organic forms than crystals built on stiff crystallographic rules.

[19] Rhodes, Mason and Sutton. *loc. cit.*

F. H. Rhodes, C. W. Mason and W. R. Sutton. "Crystallisation of Paraffin Wax." *Ind. Eng. Chem.*, 1927, **19**, 935-938.

F. W. Sullivan, W. J. McGill and A. French. "Solubility of Paraffin Wax in Oil." *Ind. Eng. Chem.*, 1927, **19**, 1042-1045.

G. A. Burrell. "Composition and Properties of Wax." *Oil and Gas J.*, 1928, **27** (22), 130.

L. D. Myers, G. Stegeman. "Solid-Solution Formation in Mixtures of Paraffin Waxes." *Ind. Eng. Chem.*, 1928, **20**, 638-641.

Y. Tanaka, R. Kobayashi and S. Ohno. "Studies on Crystallisation of Paraffin." *J. Fac. Eng. Tokyo*, 1928, **17**, 275 ; *J. Inst. Petr. Techn.*, 1929, **15**, Abstract 152.

E. Pyhala. "Die praktische Bedeutung der verschiedenen Kristallformen des Paraffins bei der Paraffinfabrikation." *Chem. Met. Zeit. die Metallboerse*, 1929, 2134-2135, 2248-2249.

E. Katz. "The Crystallisation of Paraffin Wax, Part I." *J. Inst. Petr. Techn.*, 1930, **16**, 870-888.

E. Pyhala. "Practical Experiments of Sweating Paraffin." *Refiner*, 1930, **9** (9), 92-98.

F. W. Padgett. "The Crystallisation of Petroleum Wax." *Petr. Eng.*, 1931, **2** (4), 80-84.

S. W. Ferris, H. C. Cowles and L. M. Henderson. "Composition and Crystal Form of the Petroleum Waxes." *Ind. Eng. Chem.*, 1931, **23**, 681-688.

A. N. Sachanen, L. G. Zerdeva and A. N. Vasiliev. "Properties and Structures of Paraffin Waxes and Ceresines." *Nat. Petr. News*, 1931, **23** (16), 49-52 ; (17), 68-70 ; (18), 51-53 ; (19), 71-74.

Oil Well Cementing.

Effect of Mud Admixtures with Cement and Cement Grouts.

By A. Reid (Associate Member).

Previous Work.

Certain U.S.A. workers have commented on the effect of admixtures of Rotary Mud on the tensile strength of cement. Their conclusions are given by Doherty and Manning in the *Oil and Gas Journal* for September 11th, 1930. Among these conclusions those of general interest may be re-stated. (It will be remembered that these apply most especially to Gulf Coast conditions.)

1. Small amounts of drilling mud are capable of doing considerable damage.

2. Other things being equal, equivalent mud contamination does more harm in a thin mix than in a tight mix.

3. Small amounts of mud seem to prevent setting of the cement, hence the cement is very weak and highly porous.

4. Carbonation and mud contamination are so closely associated that the carbon dioxide may be suspected of being dissolved in the mud.

5. Carbonation takes place only through moist contact of carbon dioxide with the calcium hydroxide of the cement.

6. Extensive carbonation is impossible in a properly mixed and set cement.

A very interesting table given by these workers is here repeated :

Effect of Mud Contamination on Tensile Strength of Neat Cement.

No.	Per cent. Mud.	Per cent. Water.	Pounds per sq. in. 1 day.	Tensile Strength 3 days.
1	15	50	38	100
2	10	50	55	158
3	5	50	70	175
4	3	50	83	175
5	1	50	88	188

Previous Work in Burma Fields.

Some work on mud and cement mixtures was carried out in 1926, the report on which is as follows :—

" Briquettes " (gauged 66 parts by weight of mud or water to 100 parts cement) were made with a good Portland Cement, using several different mud fluids or tap water as gauging liquid. The

results show that they have no bad effect even under these conditions of high dilution.

Tensile strengths, lbs. per sq. in.

Dilution 66 parts fluid to 100 parts cement by weight.

	Gauging fluid.	One day under water.	Three days under water.	Seven days under water.
Mud from clay	A	285	360	415
	B	270	370	430
	C	290	355	400
	D	275	350	420
	E	270	360	430
Tap water ..	—	150	360	410

Note.—(In the above it must be remembered that, as the sp. gr. of the muds was 1.2, the actual amount of water present was less in the case of the muds than in the case of tap water; it has, however, been found here before that a little mud in the gauging liquid sometimes increases the early tensile strength somewhat).

No other records of other experimental work with mud on cement were found.

Present Work.

The present work was in two sections :—

(*a*) Experiments with clays on the same lines as those recorded above.

(*b*) Experiments on the lines of Doherty and Manning (*vide supra*).

First Series of Experiments.

Briquettes were made by gauging 66 parts of 75 lbs./cu. ft. mud fluid with 100 parts cement by weight. The tensile strengths after one day, three days and seven days were determined in the usual manner.

Eight different clays were used. In one series of experiments the mud fluid was treated with 0·2 per cent. by weight of water-glass of specific gravity 1·5. Results are given in Table 1.

Table I.

Effect of mud on tensile strength of cements.

Briquettes made from 66 parts of 75 lbs./cu. ft. mud fluid to 100 parts cement by weight.

Clay used in making the grout.	Tensile strength in lbs./sq. in 66 parts fluid to 100 parts cement (untreated).			Tensile strength in lbs./sq. in 66 parts fluid to 100 parts cement (mud treated with 0.2% sodium silicate).		
	After 1 day.	After 3 days.	After 7 days.	After 1 day.	After 3 days.	After 7 days.
Sample 1	278	387	474	290	485	507
2	242	345	441	243	351	448
3	245	347	445	240	345	456
4	243	346	440	235	339	449
5	263	341	451	280	396	463
6	240	335	436	249	383	454
7	231	345	456	252	391	482
8	234	361	451	243	376	461
9	235	339	406	237	343	428

These results bear out the conclusions previously reached but, as will be clear, have only a limited applicability. In actual practice cement mixed with water may come in contact and be mixed with mud. These conditions are roughly met in the second series of experiments which will be described later.

In passing it is of interest to note that on the whole the presence of water-glass in the mud leads to a slightly higher strength of the cement and mud mix. It would seem that the contamination of cement by mud is rather less serious if the mud contains water-glass.

Second Series of Experiments.

In this series briquettes were made as follows :—Cement grouts containing 40 per cent. of water by weight were made up. Varying quantities of 75 lbs./cu. ft. mud were then added and the whole stirred thoroughly for five minutes. The tensile strengths of these mixtures after one and three days was determined. Results are given in Table 2 and graphically expressed in Figure 1.

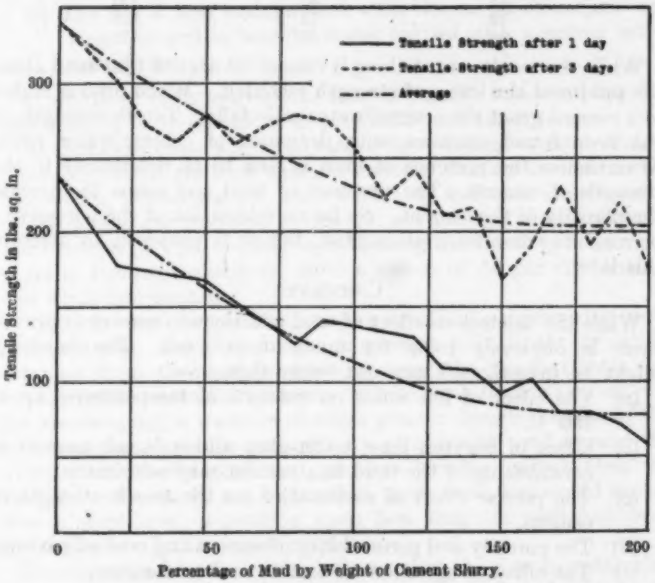


Fig. 1.

EFFECT OF AN ADMIXTURE OF ROTARY MUD ON THE TENSILE STRENGTH OF CEMENT.

TABLE II.

Percentage of 75 lbs./cu. ft. mud by weight of 40% grout.	Tensile Strength in lbs./sq. in. after 1 day.	3 days.
Nil	236	340
%		
1	210	120
2	178	301
3	174	271
4	170	261
5	167	278
6	158	260
7	141	272
8	125	279
9	141	275
10	135	257
11	132	225
12	130	242
13	108	212
14	107	217
15	92	168
16	101	193
17	80	236
18	80	191
19	72	220
20	56	175

While the results are striking it cannot be argued that mud alone has produced the losses of strength recorded. When mud is added to a cement grout the cement/water ratio falls. Tensile strength, it has been found, deceases with decreases of cement/water ratio. Nevertheless the presence of mud is seen to be deleterious to the strength of cement. The presence of mud too seems to increase the porosity of the cement. So far no estimation of the porosity or permeability has been attempted, but it is proposed to attempt this later.

COMMENTS.

While the deleterious effect of mud additions to cement is proved there is obviously room for much more work. The following might be investigated amongst other things :—

(*a*) The effect of hot muds on cements at temperatures up to 150° C.

(*b*) Effect of barytes, lime, water-glass and soda ash present as constituents of the mud in a cement-mud admixture.

(*c*) The precise effect of carbonation on the tensile strength of cement.

(*d*) The porosity and permeability of cement and mud admixtures

(*e*) The effect of agitation on cement and mud mixes.

(*f*) The action of gas on cement and mud mixes.

This paper is published by courtesy of the Burmah Oil Co., in the hope that it will stimulate the interest of cement manufacturers in Oil Well Cementing Problems.

Extinguishing and Controlling Fire on Bell and Graddy's No. 1 Daniels, Kilgore, Texas.*

By E. Stanley Durward (Member).

Before proceeding with the detailed description of the methods and equipment used to extinguish the fire and control the wild Bell and Graddy Well at Kilgore, Texas, it would be well to, first of all, make a few observations on what would appear to the writer to be general principles upon which the method of extinguishing should be based.

Two general principles are usually followed in extinguishing an oil-well fire, as follows :—

(1) The fire is extinguished and the well is brought under complete control with one operation.
(2) The fire is first extinguished with one set of operations and then the well is brought under control with a second set of operations.

It will be obvious to everyone that, if possible to accomplish, the first method is by far the more preferable and safest to use.

In almost all cases where the rate of flow, volume of sand, and all other conditions are such that no material damage is done to the well casing, cementing job, etc., a burning well that is consuming all the oil and gas produced is, in itself, not a source of much danger. For example, a wild well has been burning continuously for several years in Rumania and is no more a source of danger now than it was when first ignited.

The only real danger from such a fire is to neighbouring wells and property, and this danger is present only if gas or oil be escaping from them or they are so near the fire that their well heads may be damaged by heat. A wild well, from which oil and gas are escaping, is a source of much greater danger because of the oil in sumps and on the ground for a considerable area around the well ; if the escaping oil and gas does become ignited, then the area of the fire would not be confined to the well, but would spread over a wide area, depending upon how long the well had been flowing before ignition took place.

For these reasons the writer believes that the first consideration in deciding on the procedure to extinguish a fire should be to

* Presented before the September 24th-25th, 1931, meeting of the South-Western District of the A.P.I. Division of Production, Lufkin, Texas.

determine whether or not it is possible to accomplish an extinguishment-control job all in one, and only if this appears to be impossible should extinguishment first and control of the wild well afterwards be undertaken.

The Bell and Graddy well at Kilgore, Texas, caught fire on June 23rd, while being swabbed and cleaned, and is presumed to have been ignited from the extremely inflammable escaping gas which reached the boilers and flashed back to the well. This illustrates the absolute necessity for taking extreme precautions, in bringing in or working on wells in the East Texas Fields, to control and handle all oil and gas so that they can escape only at a safe distance from the well and from all other property, such as tank farms, etc.

The condition of the well head when the fire took place was as follows :—

The 7-in. casing was sitting on the top of the 10-in. surface string. On the top of the 7-in. casing was a casing head with two

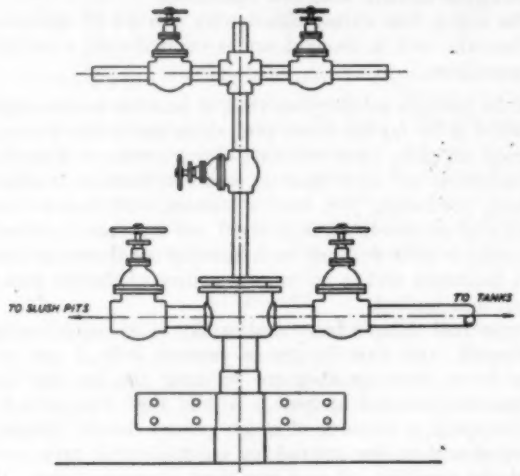


FIG. 1.
CONNECTIONS WHEN FIRE STARTED.

side outlets fitted with valves, both of which were open. From one of these a flow line led to the tanks, but the other had no pipe connections. Through the top of the casing head projected 2½-in. tubing with a tubing gate and Christmas Tree above it. The oil flow was estimated at 16,000 brls. per day, with an estimated gas

flow of 6,400,000 cu. ft., based on a gas-oil ratio of 400 cu. ft. per barrel.

Two days after the well caught fire an attempt was made to extinguish the fire with 20 quarts of nitroglycerine. This was unsuccessful, but the Christmas Tree was blown off, leaving the damaged tubing gate from which flames shot up at an angle. The gates on the side outlets of the tubing head were also damaged and the flow line was blown off.

A successful attempt was made to shoot off the tubing gate with a machine gun, and thereafter the flame from the tubing shot

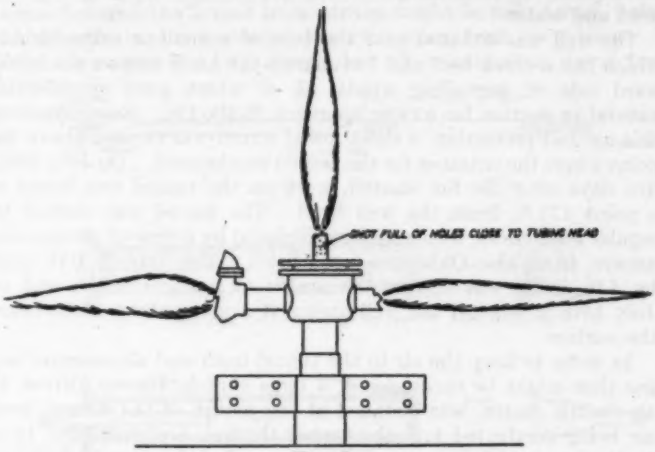


FIG. 2.

CONNECTIONS AFTER CHRISTMAS TREE AND FLOW LINES BLOWN OFF AND TUBING GATE SHOT OFF.

straight up into the air and flames shot out horizontally for a considerable distance from the two opposite side outlets on the tubing head.

The Gulf and Shell Companies, who owned the offset wells, were then requested by the owners of the Bell and Graddy well to assist them in extinguishing the fire. The well was on low ground, very close to the tanks of offset wells; a nearby creek was a possible source of danger from flowing oil and presented difficulties in damming or levee work should such become necessary, and even if dams should be built, a heavy rain might destroy them. After considering all items it was decided to extinguish the fire and kill or control it in one operation, rather than assume the risks attendant upon controlling a wild well after the fire was extinguished.

Among other schemes considered was one practically identical to that used a short time later to control the Vitex well, viz., to insert a swing pipe and nozzle into the tubing, using a gasoline powered shovel, and force water or mud or both down the tubing until it should come up around the tubing and extinguish the flames on the side openings of the tubing head, and at the same time probably kill the well. It was finally decided, in the case of the Bell and Graddy well, to use the tunnelling method, which it was considered offered more safety for the crews and permitted the installation of connections having greater volume capacity for mud and water.

The well was situated near the base of a knoll or ridge, behind which ran a creek bed, and fortunately the knoll was on the windward side of prevailing winds, all of which gave considerable natural protection for a close approach to the fire. Supplementing this natural protection, a sheet metal screen was erected above the point where the entrance for the tunnel was located. On June 28th, five days after the fire started, work on the tunnel was begun at a point 175 ft. from the well head. The tunnel was started by regular lease crews, who were later replaced by a crew of professional miners from the Oklahoma coal fields. The tunnel, 6 ft. high by 4 ft. wide, was driven downwards at a slight angle, and on July 15th it reached the well casing at a point about 25 ft. below the surface.

In order to keep the air in the tunnel fresh and also remove any gas that might be encountered, a large Buffalo Blower, driven by an electric motor, was installed at the mouth of the tunnel, fresh air being conducted into the tunnel through a canvas pipe 10 in. in diameter which was attached to the roof of the tunnel and which was lengthened as the tunnel proceeded.

A pneumatic pavement drill with digging spade was used to speed up the work, air being furnished by a portable compressor outfit. As the tunnel proceeded electric lights were strung at intervals and safety extension cords and lamps were used to light the working face.

Seepage water was encountered after proceeding a short distance. At first this was kept out of the workings by a hand pump with fire-hose discharge pipe, but later, as the quantity increased, it became necessary to install a small steam pump operated by compressed air. The pump was moved forward as work proceeded and kept close to the working face. The tunnel was heavily timbered and lined to prevent collapse. Every move was always fully considered and discussed before being carried out, and everyone was made thoroughly conversant with the plans. Speed of doing the work was subordinated to safety, and everything possible

was done to provide against an accident. The work was completed with but one slight accident, when one of the miners was hit by a falling stone; there were also two cases of heat prostration.

When the casing was reached, digging was continued until half the diameter of the 10-in. surface string was exposed. It was seen that this pipe was surrounded with 3 or 4 ins. of packed sand, etc., which had settled down round it from the surface. Several things now had to be taken into consideration. The mouth of the 10-in. casing was open at surface with the 7-in. string supported on it by a set of casing clamps and holding tension in the 7-in. The space between the 7- and 10-in. strings might be full of mud, baked hard by the heat transmitted down the casing from the surface. It might be open and, if tapped, hot oil might come down from

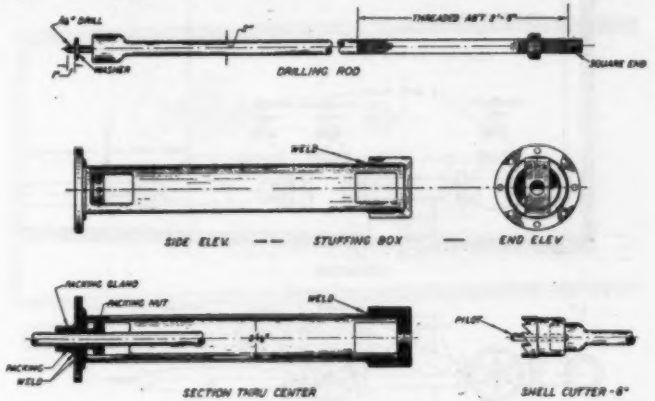


FIG. 3.

CASING DRILLING EQUIPMENT.

surface. It might be full of water from some of the artesian water sands which had broken in and washed out the mud. Was there any danger of the sand, etc., packed around the outside of the surface string caving down—it was only about 25 ft. to the surface—and allowing hot or burning oil to get into the tunnel? Some signs of steam had been seen near the base of the fire, but as the well was not drilled into the lower sand, where there might have been water, it was thought the most probable source of the water was from an artesian sand outside the 7-in., and that it had washed out the mud or had channelled up through it and was escaping from the 10-in. casing into the base of the fire.

First a 6 in. by 8 in. nipple was electrically welded to the 10-in. casing and a gate valve installed, having a nipple and flange on its

outer end. To this was bolted a special "Y" branch, having flanges on the run and threads on the branch. To this was bolted the drilling assembly, having a stuffing box and gland through which projected a spindle having a $\frac{3}{4}$-in. twist drill upon which was threaded a washer sufficiently far back from the cutting edge to allow the drill to completely penetrate the 10-in. casing, but not pass on to the 7-in. casing. After drilling a $\frac{3}{4}$-in. hole through the 10-in. casing, the drill was withdrawn beyond the gate; the gate was then closed and the drilling equipment removed. The gate was cautiously opened and hot water ran out in a diminishing

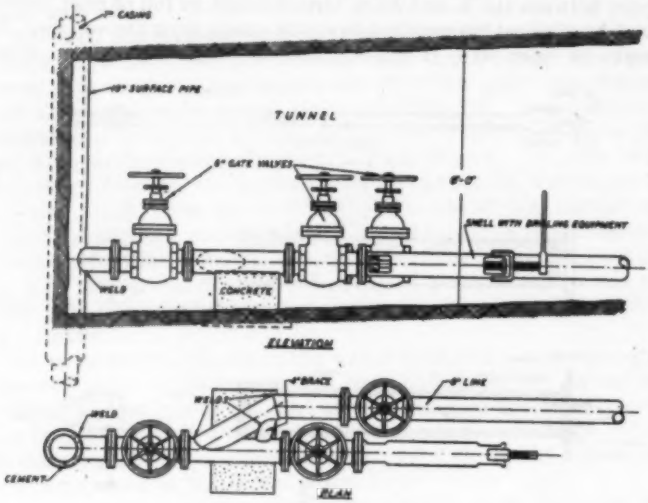


FIG. 4.

SURFACE PIPE CONNECTIONS IN TUNNEL.

stream until the flow practically ceased, thus indicating that the space between the two casings up to the surface had been emptied. It had been noticed that great piles of coke had formed around the well head, and so it was considered that entrance from the surface was well choked up and there was no danger of a downflow of hot or burning oil. ¶ The $\frac{3}{4}$-in. drill was replaced by a hollow milling tool, and the drilling equipment was then bolted in place on the run of the "Y" fitting. The mill carried a blind pilot in the centre to fit into the $\frac{3}{4}$-in. pilot hole already drilled in the 10-in. casing. A $5\frac{7}{16}$-in. disc was then cut out of the casing and withdrawn with the mill.

A 6-in. line led from the " Y " branch, out through the tunnel, and was connected to the flow tanks of an offset well. Into this line was also connected a line from the mud pumps at the offset well. As a precautionary measure 100 sacks of cement were pumped in between the 10-in. and 7-in. strings to prevent fluid of any kind coming down from above or up from below. While the cement was setting, the tunnel chamber was excavated completely around the casing. To tap on to the 7-in. casing two methods had been considered, either saddle and clamp or direct electric welding of nipples. Special all-steel forged and machined steel saddles with 6-in. nipples screwed and welded in were made, installed on a piece of 7-in. pipe and tested under 750 lbs. pressure.

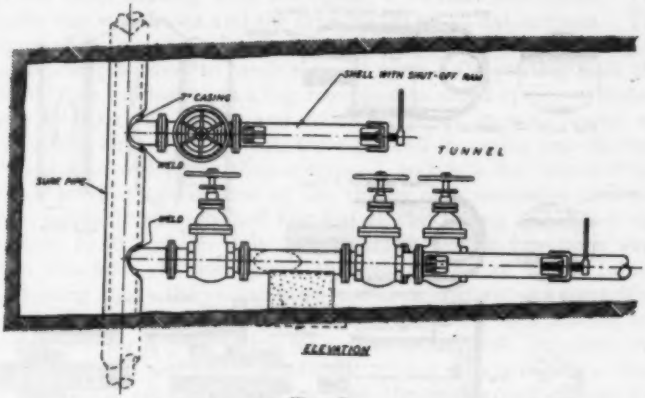


FIG. 5.

CASING CONNECTIONS IN TUNNEL.

It was intended to use these, in preference to welding on nipples, as being a safer method. When it came to the final decision, electric welded nipples were used. If the clamps and saddles had been used it would have necessitated cutting out a complete section of the 10-in. pipe. This would have left the casing above the cut-out section entirely unsupported except for the 25 ft. of friction between tunnel roof and surface. Presumably the 7-in. casing and 2½-in. tubing were supported by clamps upon the 10-in., therefore the short 25-ft. length might slide down, causing a cave-in and allowing hot or burning oil to enter the tunnel. With the welding method it was not necessary to cut out an entire section of the 10-in. casing, but only sufficient to allow of the passage of the 6-in. nipples and sufficient additional space to permit welding.

Under these circumstances the welding method was adopted. No gas was present in the tunnel. With an acetylene torch the 6-in. nipple welded to the 10-in. was cut away along with enough of the casing to allow inserting and welding 6-in. nipples on the 7-in. casing. Cement was then chipped away and the nipple welded on. A second nipple was welded on to the 7-in. about two feet above the first one. Both nipples were then tested with hydraulic pressure to 700 lbs./sq. in. and found to be tight. Valves and drilling connections were then installed in the same fashion as when drilling the 10-in. casing. Pilot holes, then $5\frac{7}{16}$-in. holes, were cut through the 7-in. casing. To the lower of the two connections the same pipe connections as were used on the 10-in.

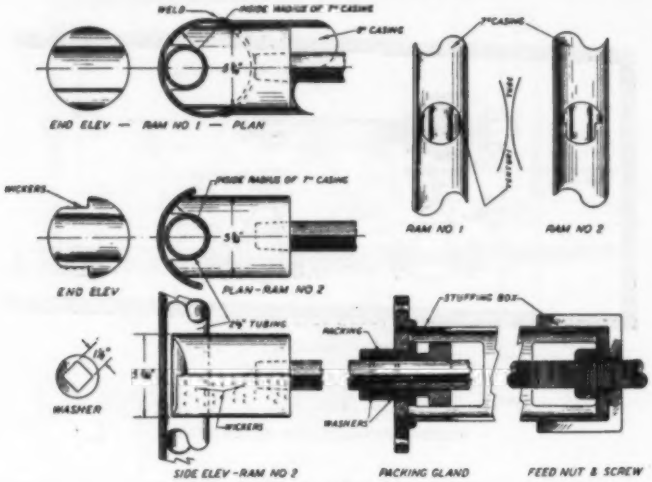


FIG. 6.

DETAIL OF RAMS.

string were connected. To the upper connection was attached an apparatus similar to the drilling outfit, with the exception that the spindle was square instead of round, and of course so was the packing gland. This square shaft was round at one end and threaded for a large nut. On the other end was a cylindrical ram or plunger very similar to a blow-out-preventer ram, having a nose curved to fit snugly against the interior of 7-in. casing and with a vertical groove to take $2\frac{1}{2}$-in. tubing.

This ram was pushed forward by the nut on the outer end. Measurements showed that it had not gone right back against the

casing, and it was thought there was a tubing collar opposite the ram, which, being grooved for the tubing, therefore could not go over the collar. The ram was withdrawn, the groove widened out to take a tubing collar, and again put back. This time it went into place. Little change, if any, was noticed in the flames from the tubing head side outlets, but as there was a great deal of smoke there might have been more change than could be detected.

Through the lower connection was now "lubricated" cement sacks, oakum, asbestos fibre, etc., followed up by water. This had no effect, as the material passed right on past the baffle in the upper connection. This was apparently due to the high velocity of the fluid around the sides of the baffle and to the circular faces of the baffle making, with the casing, a Venturi tube effect. The baffle was withdrawn and the sides milled off to flat surfaces. The sharp edges were then knicked with a chisel and centre punched to make sharp wickers to catch the sacks, etc. On putting back the baffle, then lubricating in a few Baroid sacks rolled up into cylinders and folded over double and following them up with water, an immediate shut-off of the flow through the 7-in. casing was effected. Pumping of water was then continued, and in a few minutes the water reached the bottom of the tubing and, ascending with the flow, suddenly extinguished the fire at the tubing and killed the well at 10.40 a.m. on July 20th. Casing head connections were then renewed. It was found that the nipple of 2½-in. tubing projecting above the casing head had been perforated by machine gun bullets to within an inch or so off the head, thus leaving too little space for a rethreading job. The tubing was, therefore, cut off and a solid tap screwed into the tubing as a precaution until arrangements could be made to raise the tubing and change the top joint.

This description has been made in detail to illustrate the extreme care that must be taken on such jobs and how decisions are derived at only after considering every possible situation. It must be understood that experiments on work of this character are impossible. It must be certain that, as far as is humanly possible, the procedure decided on can be carried out successfully.

CURRENT PETROLEUM NOTES.

U.S.A. Asphalt Production.—The production and importation of asphalt in the U.S.A. in 1930 amounted to about 5 million tons, showing a decrease on 1929 of about 11%. This total is made up as follows :—

Produced.	Tons.
Asphalt from petroleum of domestic origin	2,270,000
Asphalt from petroleum of foreign origin	1,976,000
Domestic bituminous rock asphalt (bit. content ca. 10%) ..	664,000
Domestic Gilsonite	37,000
Imported.	
Trinidad native asphalt	39,000
Other native and rock asphalts	14,000
Total	5,000,000

Of the petroleum asphalt figures 78·4% were solid or semi-solid grades and the balance road oils. The paving industry utilised 35% of the total petroleum asphalt, the roofing industry 27%, road oils 21·6%, cutbacks 6·2% and emulsions 0·35%. The remainder was used for miscellaneous purposes, waterproofing, briquetting, mineral rubber, pipe coatings, paints and lacquers, mastics, moulding compounds (in decreasing order of importance).

When compared with 1929 figures, it is seen that paving asphalts show a decrease of 13·5%, road oils an increase of 18·8% and cutback asphalts an increase of 102%. In spite of the reduction in the total U.S.A. asphalt production, the quantity used for road purposes has slightly increased, chiefly owing to the increased outlet that has been found for the cheaper types of paving construction, in which liquid asphalt is employed.

REVIEWS.

OIL WELL COMPLETION AND OPERATION. By H. C. George. Norman, University of Oklahoma Press, 1931. Pp. 234. $3.00.

This is described as a publication of work done under a co-operative agreement between the United States Bureau of Mines and the State of Oklahoma the author occupying the post of Director of Petroleum Engineering, University of Oklahoma.

The subject matter covers a wide field, and its presentation is somewhat unorthodox in style and arrangement. Instead of a division into chapters in the convential way, subjects are merely headed in bold type with subsidiary matter, having smaller type as heading, whilst a third class of title subdivides minor questions.

The publication is essentially a compilation of data collected from many published sources, the origin of which is generally given in a footnote, but in addition the author has frequently sought the views of recognised authorities on particular problems and their brief conclusions are incorporated. Only very casual references are made to operations outside the United States, and the very brief discussion of swabbing and bailing makes no allusion to many of the chief reasons which enforced their general employment in fields outside the United States.

Among the subjects treated are oil reservoir rocks, drilling factors bearing on production methods, casing methods, shooting of oil wells, the influence of water, gas and properties of oil in relationship to its recovery. Fifty pages are devoted to methods of controlling and handling flowing wells, and another sixty pages are descriptive of pumping problems. Oilfield emulsions, paraffination and allied troubles, cleaning of wells and fishing, all receive attention. The views expressed are those generally accepted by modern oil technologists, and there is plenty of useful material for students to digest. Although oilfield parlance and jargon are freely introduced and the subject matter is clearly presented, there is often that lack of practical touch which gives work of this nature so much life. The section on pumping is certainly the best part of the book and shows that the writer was at home when dealing with that subject.

A mass of useful data has been accumulated in a single volume of 234 pages, but there are noteworthy omissions which seem to indicate that the publication was pushed through the press incomplete. Such an important subject as air-gas lift is dismissed by a page of comment and some ten references to articles dealing with the question. No mention is made of the modern gas displacement system of production for deep wells and their automatic operation.

Three pages only are assigned to water flooding, vacuum and repressuring of oil sands under the title of "Oil Well Rejuvenation." Many of the illustrations are distinctly poor and no systematic method has been followed in the figures. On the other hand, the excellent clear type makes reading a pleasure.

A. BEEBY THOMPSON.

THE INTERNAL COMBUSTION ENGINE. By D. R. Pye. Oxford Engineering Science Series. Pp. xii. + 250. London: Clarendon Press, 1931. 15s.

This book is, as its author states in the preface, intended primarily for the student, and for the engineer before he has become immersed in the intricacies of manufacture.

It is a treatise to be read carefully from cover to cover; the careless reader cannot find summaries from section to section from which he can presume a knowledge of its contents by rapid scanning.

Earlier writers on the subject have shown how far the highest thermal efficiency obtained from an actual engine falls short of that to be expected were the working fluid a perfect gas. They had, perforce, to refer to the possible effects of change of volumetric heat, radiation, dissociation and association without being able to estimate the probable influence of these with any degree of accuracy.

The author has collected into one volume much of his own earlier work, and the most recent research on the behaviour of the fluids taking part in the engine cycle, and has been in the fortunate position of having access to a mass of experimental data of a very high order of accuracy from Ricardo and others. He is therefore able to show the extent of reduction of efficiency below that for a perfect gas which necessarily follows the use of the available working media, and to compare the possible theoretical values with the best yet reached in practice.

The factors dealt with and affecting the efficiency of an actual cycle are so numerous that it is impossible adequately to mention all in a short space, but an indication may be given of their extent.

The first section of the book treats the cycle in terms of a perfect gas, and refers to the most important defects of this method. A method is established for correcting the simple assumptions to allow for the departure of the fluids used from perfect gases as regards change of volumetric heat with temperature. A short section is devoted to the nature of the fuels used, and the consideration which must be given to their chemical structure. Determination of calorific values, and of the effect of the hydrogen content of the fuel, and also its latent heat are studied, together with the necessary calculations to allow for dissociation and association during combustion.

A chapter is devoted to detonation and the mechanism of combustion, with reference to the admirable work of Callendar, Egerton and others. Comparison of H.U.C.R.'s is included, with experimental determination of the effect of a low H.U.C.R. fuel on maximum power output over a range of compression ratios. The octane number scale of rating is mentioned in a later section. Attention is drawn to the part played by such variables as ignition advance, compression ratio, fuel/air ratio and speed on combustion, and a parallel is drawn with heavy oil engines in respect of the nature of combustion.

This is followed by the study of thermal efficiency, with allowance for all the major practical effects, separated so that each can be compared. Mixture strength, reduction of load, throttling, size and speed of engine and change of volumetric efficiency are examined, and calculated values for efficiencies are compared with actual test results.

The final section is devoted to the testing of engines, and indicates the direction which the student's experiments should take if he is to obtain the greatest value from his practical work.

If every internal-combustion engine designer were to study this book there would be much less loose talk of impossible efficiencies, and impossible fuel economies due to dopes and secret mixtures. The prevalence of vague ideas regarding engine performance is undoubtedly responsible for a large amount of misdirected energy, and the author has done valuable service in collecting and marshalling the important facts so that a fairly true picture can be obtained of just what is, and is not, possible, at least for the gas and the petrol engine.

The section on fuels would be more up to date were mention made of the use of natural-gas gasoline, aromatic extract and other constituents of modern motor fuels, and of the fact that most present day spirits are blended before distribution so that they have an octane number suited to the needs of average engines. In its existing form the impression is given that benzole is almost the only important hydrocarbon anti-knock blending agent. The value given for the aromatic content of Persian petrol should also be altered from 5% to 10%.

The table of H.U.C.R.'s for the paraffins is liable to mislead anyone approaching the subject for the first time. Had pure normal paraffins been used for the tests, it would have been found that n-nonane had the lowest H.U.C.R., and that there was a steady rise to n-pentane instead of the erratic order of H.U.C.R.'s quoted. Edgar's classification of the paraffins would have given a still more complete picture.

While the treatment of gas and petrol engines is thorough, the author is not on such firm ground with the heavy oil engine. No mention is made of the fact that the delay before combustion of heavy oils varies with the type of oil, just as the H.U.C.R. of petrols varies with the type of petrol; in fact it is suggested that the delay for heavy oils is almost constant—a statement far from the truth both for different fuels in one engine and for the same fuel in different types of engine.

Were the differing behaviour of heavy oils taken into account it is probable that many of the conclusions regarding the limiting conditions for heavy oil engines would require modification, and a wider range of experimental work must be considered, and many recent developments examined, before too much importance is attached to the analysis presented.

As regards the remainder of the book, it is not too much to say that no engine designer or research worker can afford to be ignorant of its contents.

R. STANSFIELD.

BOOKS RECEIVED.

REPORT OF THE FUEL RESEARCH BOARD FOR THE YEAR ENDED 31ST MARCH, 1931. London: H.M. Stationery Office, 1932. Pp. viii.+104. 2s. net.

An important review of the general economic principles underlying all processes for the treatment of coal by low temperature carbonisation. The products obtained from this are a smokeless semi-coke suitable for burning in the open domestic grate, a yield of gas less than that obtained from the high temperature processes, and yields of liquid fuels and tar. It is pointed out in the Report that each of these products has to compete directly with a material already on the market, and that the economic results possible with any given coal and type of plant will depend on local conditions.

The Director of Fuel Research states that it still appears to him to be true as a general statement "that the receipts from the sale of coke must at least cover the cost of the coal used, though it must depend to some extent on the receipts obtainable from tar and gas."

Low temperature coke amounts to 55–75 per cent. of the coal carbonised. As a domestic fuel it is generally more efficient than raw coal, since being smokeless more heat is radiated into the room and less lost up the chimney. It should demand, therefore, a slightly higher price than raw coal.

"The crux of the question of the national development of the new carbonisation industry," the Report goes on to state, "is the price the nation is prepared to pay for the reduction of smoke nuisance, while at the same time retaining the open domestic fire. . . . The damage and expense incurred by the burning of a ton of raw coal in the domestic hearth has been calculated to be 10s. per ton, and if this sum could be included in the balance sheet there is little doubt that the production of free-burning cokes would soon become a flourishing industry and the benefits to the country would be considerable."

"It must be remembered, however, that gas and ordinary gas-works coke are both smokeless fuels, the use of which are extending as is the use of electricity for many domestic purposes."

The Report states that the benefits to the mining industry of a general use of low temperature products would not be so great as sometimes claimed. "More coal would be mined, which would be an advantage, but the demand for household coal would be diminished, and this is the coal which fetches the highest prices."

The commercial value of the gas obtained from low temperature carbonisation plants depends entirely on the purpose for which it can be used. "Where it can be disposed of to a gas undertaking its value will not exceed the cost at the retort house; where no such outlet exists, it will only have the value of the cheapest fuel available for the particular purpose for which it is used, and this may be as low as ¼d. per therm."

The tar yield can be separated into light and heavier oils with a residue of pitch which may amount to 50 per cent. The crude tar may be used as a fuel, but it is not miscible with petroleum oils, the addition of which produces a gummy deposit. The yield of motor spirit obtained by refining processes alone is only about three gallons per ton.

The Report describes the progress made in important experiments on the conversion of tar into motor spirits and heavier oils. In one series of experiments the whole tar yield was treated with hydrogen at high pressures and temperatures, while in a second series the lighter fractions were treated with hydrogen at atmospheric pressures. In the first series, taking 20 gallons of tar as the average yield per ton of coal carbonised, 14 gallons of motor spirit were obtained, together with 6 gallons of pitch-free Diesel fuel oil. Some experiments have also been carried out on gas-works tar. The results are, so far, not as good as with low temperature tar, more hydrogen being used in the conversion into motor spirit.

In view of the extremely low market price for tar at the present time the process may be of considerable industrial importance in the future, and research on the subject is being actively pursued. The results obtained at the Fuel Research Station with a small continuous conversion plant designed for a throughput of 3–6 gallons of tar per day show that it will be possible to proceed during the coming year with the design and erection of a larger plant with every prospect of success. Further research will also be carried out on "cracking" treatments for the tars and on the treatment of the vapour from the retorts before condensation. The possibilities of the production of road tar and pitch for various purposes will also be examined.

To provide a supply of tars of known origin for the experiments it is proposed to erect at the Fuel Research Station two intermittent vertical gas ovens of the latest commercial type. These will be arranged so that it is possible to employ a range of carbonisation temperatures between 600° C. and 1000° C. (that is, intermediate between those used in current low temperature carbonisation and in gas retorts). It is thus hoped to find the optimum conditions of working in various circumstances.

The Report reviews the circumstances in which the Gas Light and Coke Company came to select the low temperature carbonisation system developed at the Fuel Research Station for a full-scale commercial trial at the Richmond Gas Works. Various causes led to the cessation of the experiments before, in the opinion of the Department and the Mines Department, a conclusive result was obtained. One of the principal difficulties encountered was the distortion of the metal retorts employed. This distortion resulted in an unduly heavy charge for replacements being added to the cost of the working of the plant. In view of the very promising results and increased throughput recently obtained at the Fuel Research Station with a brick retort, it is proposed to erect and work as steadily as possible two new retorts of that type at the Station, so as to obtain further data regarding the life and working of such retorts. With these retorts it is possible to raise the temperature of

carbonisation and to ascertain how far satisfactory free-burning smokeless fuel can be produced with the increased throughput made possible by the higher temperature.

In experiments on gas-making processes a most striking result has been obtained in connection with the working of horizontal gas retorts. Seven million tons of coal are carbonised annually by gas undertakings in such retorts. It has been found possible at the Fuel Research Station, by re-circulating the gas through the retort setting, to increase the throughput per day of the retort by 70 per cent. without increasing the temperature in the combustion chamber or materially affecting the quality or quantity of the products. This means that by comparatively cheap and minor alterations the capital value of existing retorts of this type may be nearly doubled. Industrially the flexibility of working which can be obtained through the modifications is even more important than the reductions in capital costs and ground space required resulting from the increased throughput.

The Report also records the progress made in the survey of the national coal resources of the country.